

# BULLETIN OF THE RESEARCH COUNCIL OF ISRAEL

## Section C TECHNOLOGY

*Bull. Res. Counc. of Israel. C. Techn.*

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### BOOK REVIEW

## CORRIGENDA

Preliminary note on the composition of bitter oranges of Israel

Vol. 5C, No. 1, December 1955, Page 61, line 5—6 (table):

for T.S.S./Total sugars read T.S.S. — Total sugars.



## THE UTILIZATION OF ALTERNATIVE POPULATION FORECASTS IN PLANNING

H. V. MUHSAM

*The Eliezer Kaplan School of Economics and Social Sciences,  
The Hebrew University of Jerusalem*

### ABSTRACT

Planning engineers who are the main consumers of population forecasts usually request demographers to produce a "best" forecast, while demographers prefer to present "alternative" i.e. high, medium, low, etc. forecasts.

The needs of planners can be satisfied without compelling demographers to do the impossible, if

- (1) demographers could supply their forecasts in the form of a probability distribution, i.e. attach statements of probability to their "high", "best" or "low" estimates;
- (2) engineers would establish a quantitative loss function, i.e. compute the loss suffered in case actual population figures differ by given amounts from the estimate introduced into plans;
- (3) a policy criterion is agreed upon, i.e. a mode of behaviour with respect to risks which should be run or avoided is consistently adhered to.

The utilization of alternative population forecasts in planning is thus reduced to a simple problem of statistical decision. Practical applications of this method are shown for various examples.

Population forecasts represent one of the basic elements in almost any planning problem. The population figures required by planners are often national totals and sometimes figures for a metropolitan area, for a county or for an even smaller geographical subdivision like an individual city block, or they refer to certain sections of the population of the country or of certain geographical units, such as the working population of the U.S. or the population of school age of a small urban quarter. But under all these circumstances, the planner usually requests the demographer to prepare one single estimate, to the best of his judgement and knowledge. Demographers, on the other hand, are, in general, reluctant to commit themselves to any definite number as the expected population figure at a future date; but they can often be persuaded to produce such a figure by the argument that, if they do not supply it, an estimate prepared by less competent persons would have to be used. This is the first of Davis<sup>1</sup> "persistent errors" committed in the field of population forecasts: "... the willingness of specialists to comply with urgent requests for estimates or forecasts that cannot be reliably made — many such demands should be resisted. . . "

Demographers therefore accompany their forecasts with various considerations of a quantitative or, at least, qualitative nature, which they, themselves, consider essential for the intelligent use of their figures, or they present various "alternative" forecasts. But, according to Davis<sup>1</sup>, the second "persistent error" in this field is just "... the tendency of users of such estimates and forecasts to ignore the qualifications with which they



are hedged". It is, in fact, well recognized today<sup>2</sup>, by both demographers and users of population data, that a lack of mutual understanding in this respect is one of the main problems still to be settled between demographers and their customers.

In the present paper, a method will be proposed which would enable users of population forecasts to take full advantage of the qualifications with which demographers care to accompany their predictions — under the condition that these qualifications are formulated in a suitable way. This paper might therefore serve the additional purpose of indicating to demographers a form of expressing their restrictions qualifying population forecasts in such a way that intelligent users of their figures will be able to utilize these qualifications for their own profit, above and beyond its main purpose — that of exposing such a method.

This method has already been suggested by the present author<sup>3,4</sup> at professional meetings of demographers. But, as far as we know, it has never been fully exposed nor brought to the attention of prospective users of population forecasts. The method is inspired by recent developments in statistical decision theory<sup>5</sup> and the theory of games<sup>6</sup>; but the problems encountered in the field of planning are of a particularly simple type — and we shall restrict ourselves to such simple cases in the present paper — so that the proposed reasoning can be explained on the basis of "expected values" rather than by reference to any system of decision making in the sense of Wald or of strategy in the sense of von Neumann-Morgenstern. Thus, it is obvious that the reasoning of the following has a much wider field of application than that of the use of population forecasts in planning, to which we have restricted ourselves here; it will prove useful whenever action has to be based on factual data which can be supplied only with a margin of error.

#### THE TRIPARTITE ANALYSIS OF THE PROBLEM

If the planner were supplied with an exact and reliable, unique population figure, he could quietly elaborate his plans on this basis; but he very rarely is. Thus, he is forced to consider the possibility that the actual population will turn out to be smaller or larger than the "best" estimate supplied by the demographer. The planner will therefore be concerned with the problem of computing the losses involved in having executed plans based on a lower or a higher population than will be actually existing at the time to which the plans refer. Appreciating such losses in a quantitative way results in the establishment of what we shall call the "loss function", although it is often termed in the technical literature<sup>5</sup> the "weight function". It represents the first element of our analysis.

Some considerations of this type are, obviously, almost always made, at least in a qualitative or intuitive way: most water supply engineers would weigh the disadvantage of constructing a supply system which may become insufficient for the needs of the community it is supposed to serve, before the time at which it is expected to work at full efficiency, against that of constructing a system which would not work at full capacity, at that time. If the latter disadvantage is considered less serious than the former, a certain allowance of, say, 10, 20 or 50 percent would be made on the population forecast, in order to be "on the safe side", in case the population forecast proves to be erroneous. The question then arises as to the extent of such an allowance. Should it bracket the highest believable population figure or rather leave just a small margin of safety?



It is obvious that the demographer is best fitted to supply indications as to what should be considered as reasonable limits of deviations of future actual population figures from his "best" forecast. It would, in fact, be most desirable if he could make quantitative statements as to the probability with which he expects actual population figures at the time to which his forecast refers, to fall within given limits above and below his "best" estimate. He might, e.g., be 90 percent sure that actual population figures will fall between large limits, say,  $x_{-5}$  and  $x_{+5}$ , so that there is a probability of 5 percent of getting an actual figure of less than  $x_{-5}$  and one of 5 percent of getting more than  $x_{+5}$ . Chances might be judged even for getting an actual figure within or outside a range limited by  $x_{-25}$  and  $x_{+25}$  and with respect to very narrow limits, say,  $x_{-45}$  and  $x_{+45}$ , he would be forced to admit that he estimates the odds for the actual figure to fall within such brackets, to be as low as 1:9. A complete statement of such contents, made in quantitative terms, shall be called the probability distribution; it is called technically<sup>5</sup> the distribution function. This function represents the second element of our analysis.

Actually, demographers include in their "qualifications" of population forecasts either very carefully worded statements of the type<sup>7</sup> "... it is believed that it (the actual course of events) will be between the high and the low ... series" or rather bold ones like<sup>8</sup> "... any future development, which can reasonably be considered possible, is bracketed ... within the range of projections (i.e. between the highest and the lowest forecast indicated)". Either type of statement is obviously insufficient for deriving quantitatively a probability distribution. But since 1930, when Schultz<sup>9</sup> published his studies on the probable error of the forecast from a curve, very little progress has been made in applying his concept of error in the field of population forecasts. Only very recently has an attempt been made to develop a specific theory of incorporating methods of preparing population forecasts into the frame of the theory of statistical estimation<sup>10</sup>. Yet this general theory seems to be still restricted to most simple circumstances, and it therefore may be expected to remain of little practical use for some time to come.

Instead of trying to estimate the error of their forecasts, demographers have adopted the habit of preparing "alternative" forecasts which they call, in general, "high" and "low" projections, or projections obtained by assuming various combinations of high, low and medium rates of natality, mortality and migrations. But, except in one, isolated case, that of Hyppola's population forecasts for Finland<sup>11</sup>, it has, as far as we know, never been theoretically studied nor practically attempted to attach probability statements to such alternative forecasts, although these probability statements would add most valuable information to the alternative forecasts, even independently of considerations of the type of those exposed in the present paper. Users of population forecasts can obviously do very little about this state of affairs, except for pressing on demographers to improve their methods.

Be the qualifications of a population forecast formulated as they may, how should the planner integrate the information contained in such qualifications into his projects? In other words: knowing his loss function well and having at his disposal either a complete probability distribution of the future population figure he needs, or, at least, some information as to the probability of this figure to fall short of, or beyond, certain limits, how should he determine his actions, or, as we shall call this type of behaviour,



his policy? Should he aim at avoiding, *à tout prix*, considerable loss, even if he knows the probability of the population to reach the size which would cause such big losses to be small? Or should he try to avoid any, even small, loss and prefer to run the risk of bigger losses which are unlikely to realize? In view of such alternatives, the planner must choose a policy, which forms the third element of our analysis. The selection of a well defined policy may lead to the formulation of a mathematical policy criterion.

But whereas the two preliminary steps — the study of the loss function and the estimation of the probability distribution — can be handled, with some success, at an intuitive level, very little help can be expected from choosing a policy which does not give place to a quantitative, mathematical policy criterion, which, in case the other two elements are also given in suitable form, permits a definite solution of the planning problem by appropriate mathematical methods — in the case of the policy criterion chosen in the present paper, this method will be calculus.

### THE LOSS FUNCTION

The loss function should express, in terms of dollars and cents, or other suitable quantitative units, the loss suffered by the person who follows in his action the planner's advice, in case the actual population figure (we shall restrict ourselves to the case where only one population figure referring to a future date is involved in the plans) differs from the "best" estimate supplied by the demographer and introduced in the computations of the planner. This function does not necessarily vanish in the case where actual population figures correspond exactly with the forecast; but the loss function will always have a minimum at this point.

Let us take as an example the planning of an additional water supply system for a town at present enjoying a satisfactory supply which cannot be expanded. The new supply system shall be planned in such a way as to satisfy the additional needs of the population of the town until the year  $t$ . In order to simplify the discussion, considerations concerning the future beyond the year  $t$  will be neglected. The additional population of the town which shall be served by the new system (which is supposed to work independently of the presently existing system) is estimated to the best of the demographer's knowledge and judgement to be  $x_0$ . If the supply system is then planned to serve  $x_0$  persons and the population actually numbers  $x_0$  in the year  $t$ , no loss will be suffered in the year  $t$ , because then, the system fits exactly the needs of the population.

But if in the year  $t$  the population actually numbers  $x \neq x_0$ , there will be a loss in both cases where  $x > x_0$  and  $x < x_0$ . If  $x > x_0$ , the new supply system will be insufficient and an additional system will be needed. This will be more expensive than if a bigger system, capable of satisfying the needs of  $x > x_0$  persons, would have been built at once. The difference between the costs of constructing one supply system for  $x$  persons and that of building two systems, one for  $x_0$  and one for  $x - x_0$  persons, can be considered as the loss function for  $x > x_0$ . In fact, many other considerations might, or should, be taken into consideration, in determining the loss function; but they cannot be expected to change the principles of our analysis. It should, for instance, be emphasized that the additional supply system for  $x - x_0$  persons would be constructed at a later date, so that only the present value of the sum needed for its construction should be taken into account. It might, furthermore, be mentioned, that the actual population may exceed  $x_0$  even before the year  $t$ , and that the additional system must then be

built at a time when, as a matter of fact,  $x - x_0$  is not yet known, so that additional losses will be caused by any error in estimating  $x - x_0$ . In practice, this supplementary supply system would obviously be planned so as to satisfy needs beyond the year  $t$ , but, as mentioned above, such considerations have been disregarded for reasons of simplicity.

In the case where  $x < x_0$ , a smaller supply system would have been sufficient. The loss function would, then, be the difference between the cost of building a supply system for  $x$  persons and that of building it for  $x_0$  ( $x_0 > x$ ) persons. In practice, a supply system which is too large would be considered desirable for meeting needs of a more remote future. From this point of view, the loss function for  $x < x_0$  should reflect the fact that the supply system will work, in the year  $t$ , below its full capacity, and consequently below optimal rentability. The loss thus caused to the consumers, who will be obliged to pay a higher price for the water than if the supply system fitted exactly their needs, measures the loss function for  $x < x_0$ . This loss is suffered, in fact, only in the year  $t$  and its present value would be a preferable loss function.

It should in this connection be mentioned that in any event, before the year  $t$ , the new supply system works below optimal rentability because, for all that time, the population supplied is less than  $x_0$ . Thus, the loss suffered every year before the year  $t$ , or, more exactly, its present value, should be added to the loss function. This additional loss is, by the way, smaller if  $x > x_0$  than otherwise; it causes the loss to be different from zero even in the case where there is no difference between the actual and the forecast population figures,

It might finally be taken into consideration that losses other than monetary may be caused by inappropriate planning, such as the suffering of consumers due to insufficient supply, loss of prestige of the authorities concerned because of such suffering or unjustified capital expenses, etc. But unless such losses can be converted into terms of money or the other suitable units in which losses are measured, they cannot be accounted for in the analysis proposed here.

The type of the loss function to be expected under the circumstances of the present example is shown in Figure 1 (A). It decreases for increasing values of  $x$ , as long as  $x < x_0$ , and reaches its minimum for  $x = x_0$ ; at this value of  $x$ , the function has a point of discontinuity, jumping up to a higher value which expresses the loss involved in constructing an additional supply system. The function then decreases perhaps very slowly, because the loss involved in constructing two systems instead of one will become less considerable the bigger the second system. This loss function can be approximated by a simpler function, composed of straight sections only and shown in Figure 1 (B).

Some other simple loss functions which might be encountered under various circumstances are shown in Figure 1 (C), (D) and (E). The loss function will be designated by  $L = L(x, x_0)$ , being a function of both  $x_0$ , the population figure used in planning, and  $x$ , the ultimately observed population figure, and is, in general, a function of the difference  $x - x_0$ .

#### THE PROBABILITY DISTRIBUTION

Whereas the loss function can be deduced from the results of costing, deferred payments and similar considerations, no theoretical basis for establishing the probability distribution of population forecasts is supplied by demographic theory. One school



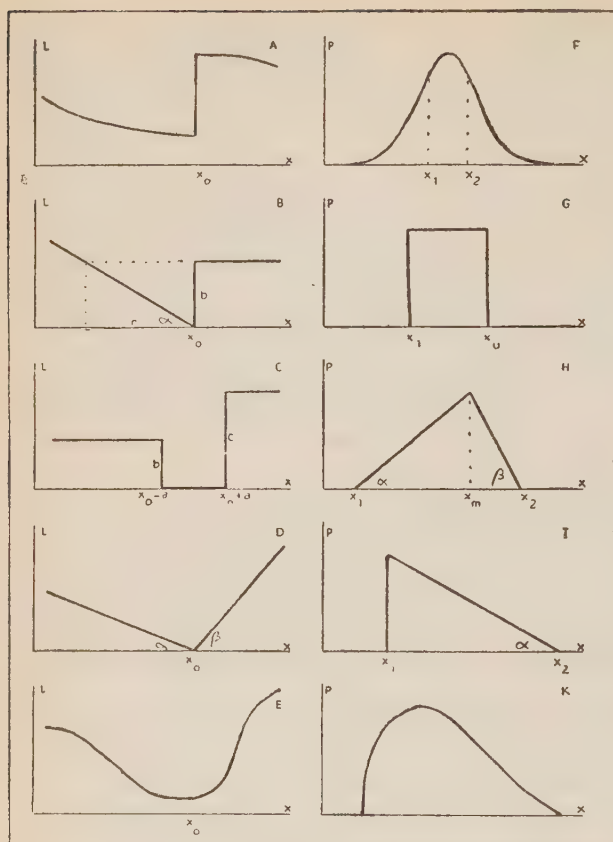


Figure 1

Schematic examples of loss functions (left) and probability distributions (right).

being  $m = 1/2 (x_1 + x_2)$ . The equation of the probability distribution, which we will call here  $P = P(x)$ , would then be

$$P = \frac{1.35}{(x_2 - x_1) \sqrt{2\pi}} e^{-\frac{1}{2} \left( \frac{1.35(x-m)}{x_2 - x_1} \right)^2} \quad (1a)$$

If the probability, for the actual figure, to fall within the range delimited by the low and high projections is not estimated to be even, the coefficient of conversion of this range into the standard deviation would not be 1.35... but could be read, in accordance with the estimated level of probability, from published tables of the integral of the normal curve of errors.

It should be emphasized that the very fact that the estimate of the probability for the actual figure to fall within certain limits is a conjectural or intuitive statement, should not be considered to impair the theoretical validity of the method. It has, in fact,

of thought might postulate that this distribution should follow the normal curve of errors (see Figure 1 (F)). If this postulate is accepted as a working hypothesis, it would be sufficient, for establishing the whole probability distribution, if the demographer supplied a higher and a lower forecast (say,  $x_2$  and  $x_1$  respectively) and assumed responsibility for appreciating the probability with which he expects the actual figure to fall within these limits. If he considers this probability to be, say, 50 percent, or, more exactly, actual population figures as likely to fall within these limits as outside, and, at the same time, the risk of finding them to lie, actually, above the higher limit and that of finding them beneath the lower to be even, then the range  $x_2 - x_1$  can be assimilated to the interquartile range of a normal distribution or about 1.35... times its standard deviation, the mean

been shown by Koopman<sup>12</sup> that such statements of intuitive probability give place to as valid a theory of probability as classical probability statements based on the concept of "equally likely events" or similar foundations of the theory of probability. What appears to be more questionable is, whether the probability function can be assumed to be the normal function of error and, even, whether it can be supposed to be at least symmetrical. Experience has shown that certain elements which enter into the computations of population forecasts admit wide deviations from their most probable values to one side, but are not liable to deviate to any considerable extent in the opposite direction. Take immigration into the U.S. as an example. If a "best" forecast assumes, e.g., an immigration of 100,000 persons per annum, a low forecast could not reasonably assume less than no immigration, while a high forecast may well take into consideration as high a figure as, say, 300,000 persons per annum, as actually admitted in 1924—1928.

It seems, therefore, reasonable to admit probability distributions, other than the normal curve of errors, and, as none can be theoretically justified, any one can be assumed to be as valid as another. Thus, preference can be given to simple functions which can easily be handled mathematically and yield fairly general results in further mathematical analysis. It will also be shown that the form of the probability function often does not affect very seriously the final result of the decision in planning problems: the location and the width of the range are the main factors involved.

Under these circumstances, a very simple, rectangular probability distribution (Figure 1(G)) could be considered as a satisfactory, mathematical translation of a statement of the type: "the population would certainly come within limits  $x_1$  and  $x_u$ , but there seems very little reason to expect it at any particular point within this range." A triangular probability distribution (Figure 1(H)) would correspond to a statement like: " $x_m$  is the best estimate, but it is very unlikely that the population would be less than  $x_1$  or exceed  $x_2$ ". Statements of other types might give place to probability distributions of the types shown in Figures 1(I) and (K).

#### THE POLICY CRITERION

Let us assume a loss function  $L = L(x_0, x)$  and a probability distribution  $P = P(x)$  to be given. We can thus ascertain the probability of being concerned at the time  $t$  with a population  $x$  and we know the loss which will be suffered if a population forecast  $x_0$  has been introduced into planning considerations instead of the actual, obviously still unknown, figure  $x$ .

There are, then, different possible policies of choosing the most convenient value  $x_0$ , each of which could be logically or economically justified and actually followed in practice. Only one policy will be exposed here, and its mathematical criterion be deduced. Although this policy has certain undeniable advantages, the very fact that it is the only one exposed here should not be interpreted as an attempt to recommend it as the most suitable for any and all purposes. This policy is called in general that of "minimizing the expected loss", but we would prefer to call it the policy of minimizing total loss in the long run. This policy can be grasped easily by considering many planners who are faced with the same problem of choosing the best value of  $x_0$  in view of identical loss functions and probability distributions. It can be expected that, in

the combined experience of all these planners, any population figure  $x$  will realize relatively as frequently as its probability to realize ( $P(x)$ ) had been estimated by the demographer. In the combined experience of these planners the loss  $L(x, x_0)$  will therefore occur  $P(x)$  times, and the total loss of all these planners together, who all used in their plans the most profitable population forecast  $x_0$  which is the unknown of the problem, will be obtained by summing products  $P(x)$  times  $L(x_0, x)$  for all planners, or, equivalently, for all values of  $x$ . Symbolically, the total loss, or, as it is technically called<sup>4</sup>, the risk, function is thus given by

$$R = \int_{-\infty}^{+\infty} P(x) L(x_0, x) dx$$

This total loss depends obviously on the population forecast  $x_0$  which had been accepted by all the planners. "Minimizing expected loss" or "total loss in the long run" would mean choosing the value of  $x_0$  for which the total loss  $R$  has a minimum, if considered as a function of  $x_0$ . The value of  $x_0$  for which  $R$  is minimum is obviously obtained by solving the equation

$$\frac{\partial R(x_0)}{\partial x_0} = 0 \quad (1)$$

for  $x_0$ . This is our policy criterion. The value of  $x_0$  thus obtained would ensure minimum loss to all the hypothetical planners considered. But, at the same time, a figure  $x_0$  thus determined at all occasions any given planner is faced with such a problem, would result in minimum total loss to this individual planner, and it would therefore be profitable to adhere to this method at each occasion, wherever a choice of this type has to be made.

It might again be reminded that equation (1) is not the only possible or advisable policy criterion.

Other policies might be based on the principle of arriving at minimum loss in each case, i. e. constructing the water supply system of our example so as to fit exactly the "best" forecast, or on that of avoiding the maximum loss, or, in our example, to build the supply large enough to make it practically impossible that the population becomes larger than expected. But it is obvious that in the former case no margin of safety is provided, and in the second one unnecessary capital expenses will be often made. Such other policies would evidently call for different policy criteria.

In any event, a loss function, a probability distribution and a policy criterion, suitably chosen, can be expected to produce a unique solution to the problem of selecting the most recommendable population forecast from within the range of possible figures indicated by the demographer.

#### SOME EXAMPLES

A very simple, in fact, trivial, situation arises when the loss function is nil, for a certain range — of width  $2a$  — of actual population figures, and constant for both higher and lower figures, i.e. of type (C) of Figure 1, and the probability distribution is zero for all values of  $x$  outside a certain range (from  $x_1$  to  $x_u$ ) and constant within this range or of a rectangular shape (Figure 1(G)). If the range for which losses are nil is wider



than, or equal to, the range bracketing possible population figures (i.e.  $2a \geq x_u - x_1$ ), the solution becomes trivial: any value of  $x_0$  for which the segment  $x_1 \bar{x}_u$  remains within the range of zero loss will prevent any loss, i.e. all values of  $x_0$  between  $x_1 + a$  and  $x_u - a$  will ensure zero loss. But if  $x_u - x_1 > 2a$  and the loss in case of a population less than  $x_0 - a$  being  $b$ , and in case of a population of more than  $x_0 + a$  being  $c$ , it will be evidently most advantageous to have as much as possible of the range from  $x_1$  to  $x_u$  within the area  $x_0 - a$  to  $x_0 + a$ , and all the rest of the range  $x_1$  to  $x_u$  in the area of the smaller of the two losses  $b$  and  $c$ . Thus, if, say,  $b < c$ , the optimal value of  $x_0$  (which we shall call  $\hat{x}_0$ ) would be

$$\hat{x}_0 = x_u - a \quad (2)$$

Very simple but less trivial situations arise if a loss function which decreases linearly for actual population figures smaller than  $x_0$  and increases also linearly for figures above  $x_0$  (i.e. of the type shown in Figure 1(D)) is combined with a rectangular probability distribution (see Figure 1(G)), or a rectangular loss function (Figure 1(C)) is combined with a triangular probability distribution (Figure 1(H)).

The latter combination can be considered as a slight modification of the trivial case discussed above. Here, as there, the solution is trivial, as long as  $x_2 - x_1 \leq 2a$ . But if  $2a < x_2 - x_1$  the total loss function is

$$R = \int_{x_1}^{x_0 - a} bd(x - x_1) dx + \int_{x_0 + a}^{x_2} ec(x_2 - x) dx$$

where  $d = \tan \alpha$  and  $e = \tan \beta$  are the slopes of the sides of the triangular probability distribution. Integration yields

$$R = \frac{bd}{2} [(x_0 - a)^2 - x_1^2] - bdx_1(x_0 - a - x_1) + cex_2(x_2 - x_0 - a) - \frac{ce}{2} [x_2^2 - (x_0 + a)^2]$$

and, by derivation,

$$\frac{\partial R}{\partial x_0} = x_0(bd + ce) - (bda + bdx_1 + cex_2 - cea) = 0$$

Thus the optimal value of  $x_0$  is

$$\hat{x}_0 = \frac{bd(x_1 + a) + ce(x_2 - a)}{bd + ce}$$

In case of a symmetric probability distribution,  $d = e$ , and

$$\hat{x}_0 = \frac{b(x_1 + a) + c(x_2 - a)}{b + c} \quad (3)$$

is a simple weighted average of  $(x_1 + a)$  and  $(x_2 - a)$  weighted with  $b$  and  $c$  respectively. This can be considered as a slight amendment of the trivial result obtained in the

first example with an identical loss function, but a probability distribution of a very different shape. The comparison of the results obtained in these two examples may thus throw some light on the effect of the shape of the probability distribution on the optimal population forecast  $\hat{x}_0$ . In the former example, i.e. with a rectangular probability function, it has been shown that, if  $x_u - x_1 > 2a$  and  $b < c$ ,  $\hat{x}_0 = x_u - a$ . Here  $\hat{x}_0 = x_2 - a$  only if  $b \ll c$ , otherwise the optimal population assumption is a weighted average of  $x_2 - a$  and  $x_1 + a$  as shown in (3). It can thus be concluded that, at least in this example, the shape of the probability distribution does not affect the optimal population assumption in a very decisive manner. It could furthermore be argued in this connexion, that the rectangular probability distribution which fits best the equilateral triangular function extending from  $x_1$  to  $x_2$  would be a rectangular function which is different from zero for a shorter range than from  $x_1$  to  $x_2$ . Purely geometrical considerations would suggest the range from

$$x_l = x_1 + \frac{1}{2} (x_2 - x_1) \left(1 - \frac{1}{\sqrt{2}}\right)$$

to

$$x_u = x_2 - \frac{1}{2} (x_2 - x_1) \left(1 - \frac{1}{\sqrt{2}}\right)$$

so that the optimal population assumption for the rectangular probability distribution which corresponds to the case of the triangular distribution from  $x_1$  to  $x_2$ , would rather be

$$\hat{x}_0 = x_2 - a - \frac{1}{2} (x_2 - x_1) \left(1 - \frac{1}{\sqrt{2}}\right)$$

This expression should be compared with the above formula (3) which can easily be transformed into

$$x_2 - a - (x_2 - x_1) \frac{b}{b + c}$$

The rectangular probability distribution would thus lead to exactly the same result as the triangular distribution, whenever  $b/c = \sqrt{2} - 1$ , or  $c$  exceeds  $b$  approximately 2.4 times.

If the triangular probability distribution is not symmetrical, the optimal value of  $x_0$  is still a weighted average of  $x_1 + a$  and  $x_2 - a$ , but the weights are then affected by the amount of skewness of the triangle, too.

In the case of the former combination, that of a loss function of type (D) (Figure 1) combined with a probability distribution of type (G) (Figure 1), again, the value of  $x_0$  which promises minimum loss in the long run is a weighted average of the upper and lower limits of the range of possible population figures, weighted with the slopes of the corresponding branches of the loss function. If these slopes are equal, the most profitable assumption regarding population ( $\hat{x}_0$ ) to be introduced in the planning project is the arithmetic average of the limit values indicated by the demographer. If the gradient of the loss function is, say, lower for negative deviations of actual population figures from the forecast, and higher for positive ones, i.e. the loss increases slowly if the actual population falls short of expectation and it increases quickly in case

the population figures exceed the forecast, it would be more advisable to use a population figure nearer to the upper of the possible limits indicated by the demographer. This sounds most reasonable, and most planners would have acted so also without mathematical analysis. But if there is any non-negligible loss in case of the actual population falling short of the medium forecast, the choice of the upper limit as working hypothesis, which planners might be inclined to make in order to "be on the safe side", would not be an optimal choice for the decision policy proposed here.

Somewhat more realistic but still hypothetical circumstances can be exemplified by a loss function of the shape explained above on the basis of the example of the planned water supply system and shown in schematic form in Figure 1(B). In order to keep mathematics simple and the result easy to interpret in non-mathematical terms, the probability distribution will be supposed to be of a triangular, but extremely positive-skew, shape shown in Figure 1(I). This type of a probability distribution corresponds to a verbal statement of the kind: "the population is expected to reach a figure  $x_1$ ; it is extremely unlikely to fall short of this figure, but it might well exceed it up to a limit  $x_2$ ". If we designate the slope of the loss function up to its minimum at  $x_0$  by  $a = \tan \alpha$ , and its constant value beyond  $x_0$  by  $b$ , and the slope of the descending side of the triangular distribution by  $c = \tan \alpha$ , we have the loss function

$$L = \begin{cases} a(x_0 - x) & \text{for } x \leq x_0 \\ b & \text{for } x > x_0 \end{cases}$$

and the probability distribution

$$P = \begin{cases} 0 & \text{for } x_2 < x < x_1 \\ c(x_2 - x) & \text{for } x_1 \leq x \leq x_2 \end{cases}$$

The total loss function is then given by

$$R = \int_{x_1}^{x_0} a(x_0 - x) c(x_2 - x) dx + \int_{x_0}^{x_2} bc(x_2 - x) dx$$

Integrating, we obtain

$$R = ac \left[ \frac{x_0^3 - x_1^3}{3} - \frac{(x_0 + x_2)(x_0^2 - x_1^2)}{2} + x_2 x_0 (x_0 - x_1) \right] + \tag{12}$$
$$+ bc \left[ x_2 (x_2 - x_0) - \frac{x_2^2 - x_0^2}{2} \right]$$

and the derivative with respect to  $x_0$  is

$$\frac{\partial R}{\partial x_0} = - \frac{ec}{2} x_0^2 + (cax_2 + cb) x_0 + \frac{ac}{2} x_1 (x_1 - x_2) - bcx_2 = 0$$
$$\therefore \hat{x}_0^2 - 2 \hat{x}_0 \left( x_2 + \frac{b}{a} \right) + x_1 (x_2 - x_1) + \frac{b}{a} x_2 = 0$$

Let us call  $r$  the difference between  $x_0$  and the population figure  $x$ , smaller than  $x_0$ .



for which the loss function reaches the same level as for population figures above  $x_0$ , i.e.  $r = b/a$ . Then

$$\hat{x}_0^2 - 2 \hat{x}_0 (x_2 + r) + x_1 (x_2 - x_1) + r x_2 = 0$$

and

$$\hat{x}_0 = x_2 + r \pm \sqrt{(x_2 + r)^2 - (x_2 - x_1) x_1 - r x_2}$$

For further simplification we put  $r/(x_2 - x_1) = s$  and, without losing in generality,  $x_1 = 0$ . Then,

$$\hat{x}_0 = x_2 (1 + s \pm \sqrt{1 + s + s^2})$$

The optimal population assumption depends only on  $x_2$ , the upper limit of the demographer's possible range, and on  $s$ , which is the ratio between the negative deviation of actual population figure from the accepted forecast for which the loss equals the constant loss suffered in case of a positive deviation and the range of possible population figures as estimated by the demographer. The solution is, in fact, unique, because, as  $x_0$  must obviously be smaller than  $x_2$ , only the negative root can be expected to yield a meaningful solution. Thus, there is only one population figure which, assumed by the planner, complies with our policy, although the criterion results in a quadratic equation in  $\hat{x}_0$ . The negative root gives always a value of  $\hat{x}_0$  greater than zero (or, in fact, greater than  $x_1$ ) and smaller than  $x_2$ , because for all positive values of  $s$ ,  $0 < 1 + s - \sqrt{1 + s + s^2} < 1$ . This expression increases monotonously from 0, for  $s = 0$ , and approaches 0.5 asymptotically for  $s \rightarrow \infty$ .

It should be pointed out that, already for fairly small values of  $s$ , the expression  $1 + s - \sqrt{1 + s + s^2}$  approaches its asymptotic value of 0.5 closely. For  $s = 4$ , e.g., it assumes the value 0.417, and for  $s = 10$ , already 0.474. It can therefore be concluded that under the assumptions of the present example, and if, in addition,  $s$  is large (or, in other words, if the ascending branch of the loss curve (for  $x < x_0$ ) remains below the level of loss suffered in case of actual population figures exceeding the assumedly best forecast, for a range  $r$  which is large as compared with the range  $x_1$  to  $x_2$  of possible population figures as estimated by the demographer), the use of a population estimate, approximately half way between the limits ( $x_1$  and  $x_2$ ) given by the demographer, will ensure minimum expected loss to the planner.

But in the present example, the effect of various parameters of the loss function and the probability distribution on the optimal population figure for planning purposes is, in general, not of the type of simple — direct or indirect — proportionality as observed in the simpler examples considered previously. The general result could not therefore be so easily obtained by intuition. This will obviously be the position in less schematic situations with which the planner will be concerned in practice. The various examples exposed above were mainly given in order to prove that explicit solutions can be arrived at under various circumstances, that the solutions thus obtained sound reasonable in view of the actual practice guided by intuitive methods.

and that, at the same time, relationships between the optimal population figure and the various parameters of the loss function and the probability distribution are not always of a very simple character. It is obvious that the results actually obtained in these examples may prove to be of little practical use to planners. But they are assumed to exemplify the proposed method, so that the planner shall be able to obtain the required result for any specific problem by applying the method to his own data.

### CONCLUSIONS

The computations carried out in the various examples lead, for each of the situations considered there, to a unique conclusion regarding the population figure which should be accepted for planning purposes in order to ensure largest advantage — or minimum loss — to those who eventually carry out the plans. In practice, such computations may often not yield general solutions of the type obtained here, but numerical solutions will always be obtainable if the following three data are available:

(a) The loss function, i.e. a rule which permits to compute or to estimate, for any deviation — positive or negative — of the actual population figure from the forecast, the loss caused to the person who followed the planner's advice by such a deviation.

(b) The probability distribution of the population forecast, i.e. a function which shows the probability, intuitive or computed, of the population to reach, at the period under consideration for the planning problem, any figure or to fall within certain limits.

(c) A policy criterion, which defines clearly which risks the planner is ready to run, and which he wishes to avoid or prefers to minimize.

It should be emphasized that the establishment of the loss function and the estimation of the probability distribution are strictly determined, in theory, at least, by technical and scientific considerations, although, in practice, they may often be founded on intuitional methods, conjecture or similar procedures. But whereas with respect to the loss function no major methodological problem arises, demographic theory is, as yet, not capable of supplying a basis for deducing probability distributions of population forecasts. On the other hand, the considerations leading to the establishment of a policy are of a purely subjective and conventional character: one policy might appeal to one person or be agreed upon by a group, while another might appear preferable to others. Furthermore, it is obvious that not every policy can be translated into a mathematical policy criterion. But certain reasonable policies, like that of minimizing expected loss used in the present considerations, give place to a criterion which is easily expressed in mathematical form and, if applied to a situation, suitably defined by the loss function and the probability distribution, leads to a unique solution of the problem.

In fact, opinions regarding policy do not differ as much as they could. Thus, the main deficiency of the method of analysis as a whole is the inability of demographers to supply the necessary data in the requested form. But there can be very little doubt that the repeated requests of users of population forecasts to be supplied with such forecasts, presented in the form suitable for decision analysis, will induce demographers to develop necessary methods. It is hoped that the present paper will also contribute to this aim.

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# HEAT AND MASS TRANSFER ON THE OUTSIDE OF COOL AIR DUCTS

R. LANDSBERG

*Faculty of Mechanical Engineering, Technion — Israel Institute of Technology, Haifa*

## ABSTRACT

The usual heat transfer computations based on dry air film coefficients are inadequate for cool air ducts in warm surroundings with appreciable outside humidity. Sweat-water formation increases the heat transfer considerably. This mass transfer depends on diffusion actuated by the difference between the dew point of the surrounding air and the surface temperature of the air duct.

Equations and diagrams for the heat and mass transfer under conditions prevailing in air conditioning practice are developed.

The losses caused by the absence of heat insulation on cool air ducts are usually considered as a mere heat transfer problem depending on the film coefficients on both sides of the metal<sup>1</sup>. It will be shown, however, that sweat-water formation due to the condensation of humidity from the surrounding air may have a far greater influence on heat transfer than equations for dry air suggest.

The condensation problem is of practical importance for air conditioning plants where air of 10 to 15°C is carried through ducts for which insulation is rather expensive. Economically it is arguable that in view of the comparatively short operating time of such plants — usually just over 1000 hours per year — a certain loss of efficiency could be balanced against the saving of initial outlay. However, the formation of water drops, which could lead to the deterioration of building materials, must obviously be avoided. The thermal conditions and possible extent of such condensation should therefore be clarified.

The typical situation may be represented as follows:

Cool air flows through a sheet metal duct surrounded by warm air, for instance in the attic of a building. Neglecting the heat resistance of the duct material and assuming the relative humidity of the outside air to be the only variable, two ranges of conditions can be distinguished:

$$(I) \quad t_s > t_D; \text{ no condensation, therefore} \\ h_i(t_s - t_i) = h(t_0 - t_s) \quad (1)$$

The film coefficients can be determined both for the air flowing inside the duct<sup>2</sup> and for still air outside<sup>3</sup> (constants for metric units):

$$h_i = 0.04 (N_{Pe})^{0.75} \frac{k}{d}; \quad N_{Pe} = wd/\alpha \quad (2)$$

$$h = 2.2 (t_0 - t_s)^{0.25} \quad (3)$$

This will lead to only one possible value of  $t_s$  for the lower range of humidities until  $t_s = t_D$  and condensation just begins.

$$(II) \quad \begin{aligned} & t_s < t_D ; \text{ and} \\ & h_i(t_s - t_i) > h(t_0 - t_s) \end{aligned}$$

The latter inequality means that the temperature potential between the duct and the air inside will allow the transfer of a greater heat quantity than that determined by the temperature drop between the outside air and the duct surface. Therefore condensation will occur so that

$$q'' = h_i(t_s - t_i) = h(t_0 - t_s) + m''r \quad (4)$$

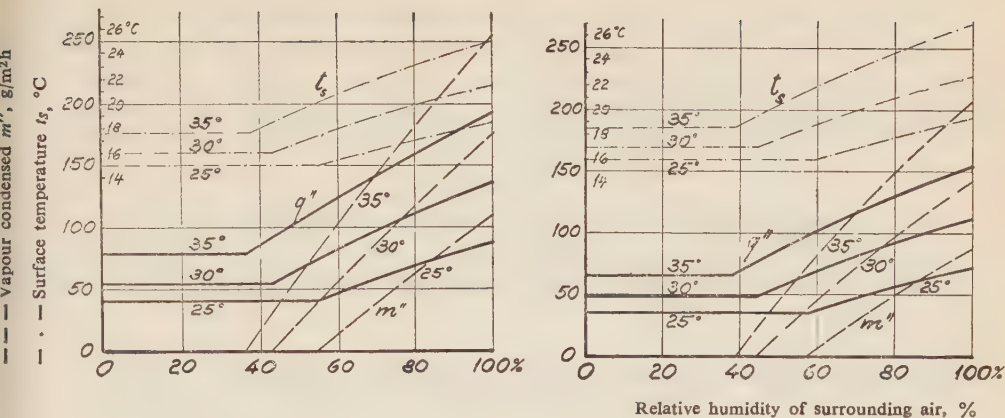
The condensing quantity is, however, limited by the ability of the outside air to supply the heat quantity postulated by  $h_i(t_s - t_i)$  by means of heat transfer plus water vapour which must reach the cold metal face through diffusion. The mass transfer is determined by diffusion conditions in the surrounding air<sup>4</sup>

$$m'' = h \frac{\delta(P_0 - P_s)}{\alpha\gamma c_p RT_m} \quad (5)$$

$$q'' = h \left[ 1 + \frac{\delta r(P_0 - P_s)}{\alpha\gamma c_p RT_m (T_0 - T_s)} \right] (T_0 - T_s) \quad (6)$$

The original equation has been simplified here since the ratios of the absolute temperatures and of the molecular weights of air near the surface and at a greater distance will not materially differ from unity. Eq. (4) combined with (5) or (6) constitutes in effect — since  $h$  is dependent on the 4th root of a temperature difference — an equation of the 4th degree for  $t_s$ . In addition,  $P_s$  and to a slight extent also  $\gamma$ ,  $r$  and  $T_m$ , vary with  $t_s$ . The equation can be solved by trial and error, assuming a value of  $t_s$  and correcting until eq. (4) yields the same heat flow  $q'' = h_i(t_s - t_0)$  as eq. (6).

Calculations have been carried out for surrounding air temperatures of 25, 30, and 35°C, and cooled air of 12.5°C inside the duct, with two different air ducts, one of  $1 \times 1$  m with 9 m/sec air velocity, the second  $0.5 \times 0.5$  m with 4.5 m/sec, corresponding to inside film coefficients, as determined by eq. (2), of 15.1 and 10.7 kcal/m<sup>2</sup>h°C, respectively. Figures 1 and 2 show the results as functions of the relative humidity of the surrounding air. Numerical values used are:  $\alpha/\delta = 0.92$  according to Jakob<sup>4</sup>;  $c_p = 0.24$  kcal/kg°C;  $r = 600$  kcal/kg, and other figures according to the usual tables.



Figures 1 and 2

Heat and mass transfer relations for two air ducts.

Figure 1 (left): Duct  $1 \times 1$  m; air velocity 9 m/sec.

Figure 2 (right): Duct  $0.5 \times 0.5$  m; air velocity 4.5 m/sec.

Temperatures near the curves indicate the surrounding air temperature for which the curve is valid. Cool air temperature in all cases  $12.5^{\circ}\text{C}$ .

Example: Given surrounding air of  $30^{\circ}\text{C}$ , 60% r.h., duct as per Figure 1. Read from curves marked  $30^{\circ}$ :  $m' = 55$  g/m<sup>2</sup>h;  $q'' = 81$  kcal/m<sup>2</sup>h;  $t_s = 18^{\circ}\text{C}$ .

The equations used for the outside of the duct are valid for vertical surfaces only. Equations for heat transfer *from* horizontal plates are available, but their applicability for heat mass transfer *towards* the surface is doubtful. As an approximate solution, it may be assumed that — as pointed out by Jakob<sup>5</sup> — the arithmetic mean of the film coefficients for top and bottom very nearly equals the film coefficient for a vertical plate of the same dimensions. The total heat transfer to a square duct can thus be computed directly by multiplying the value read from the curves by the actual duct surface.

The practical conclusion would be that the use of non-insulated metal air ducts at temperatures approaching  $30^{\circ}\text{C}$  and appreciable humidity involves a definite risk of sweat-water formation which must be avoided. Moreover, the heat gain of the cool air may seriously interfere with the performance of the air-conditioning plant. With the mass flow determined by duct size and air velocity, this heat gain can be calculated. In the case of a  $0.5 \times 0.5$  m duct and, as an example,  $q'' = 60$  kcal/m<sup>2</sup>h read from the curves in Figure 2, it will amount to 0.24 kcal/kg or  $1^{\circ}\text{C}$  temperature rise for about 10 m duct length. The possible increase of the external heat transfer due to air movement should also be borne in mind<sup>6</sup>.

The calculation of the thickness of insulation required to avoid condensation is elementary. A  $1\frac{1}{2}$ " insulation of normal insulating board with a conductivity of 0.04 kcal/mh $^{\circ}\text{C}$  will normally raise the surface temperature above the dew point and — in the example quoted — reduce the heat gain by more than one half.



As mentioned earlier, the curves are based on cool air of 12.5°C. Since vapour pressure is not a linear function of temperature, the curves are not strictly valid for equal temperature differences at other temperatures but probably sufficiently accurate within the range occurring in air conditioning practice.

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## LIST OF SYMBOLS

$d$	= diameter, or length of one side of a square
$h$	= film coefficient of heat transfer in still dry air
$h_i$	= id. for air flowing inside duct
$k$	= thermal conductivity of air
$m''$	= quantity of condensing vapour, weight per unit surface and time
$N_{Pe}$	= Peclet's number
$P_0$	= partial vapour pressure in surrounding air
$P_s$	= id. at temperature of duct surface
$q''$	= heat transfer per unit surface and time
$r$	= latent heat of vaporization
$R$	= gas constant for water vapour
$t_0, T_0$	= temperature of surrounding air (°C, °K)
$t_D$	= dew point temperature for surrounding air
$t_i$	= temperature of air flowing inside duct
$T_m$	= $(T_0 + T_s)/2$
$t_s, T_s$	= surface temperature of duct material (°C, °K)
$w$	= air velocity in duct
$\alpha$	= thermal diffusivity of air
$\gamma$	= specific weight of surrounding air
$\delta$	= mechanical diffusivity of air

# INFLUENCE OF CLIMATIC FACTORS ON CRANE MOTOR POWER IN ISRAEL

P. W. ERNST

*Faculty of Mechanical Engineering, Technion—Israel Institute of Technology, Haifa*

## ABSTRACT

In hoisting equipment, motor rating is determined by the maximum safe working load, frequency of use, and speed. Travelling cranes are mainly operated by means of internal combustion engines or by hand. The paper discusses the influence of regional climatic factors on annual regional averages. Seasonal deviations from the standard output are calculated with the aid of a new formula.

## OPERATION OF HOISTING EQUIPMENT

In hoisting equipment, motor rating is determined by the maximum safe working load, frequency of use, and speed. In order to avoid excessive structural stresses, as well as for economic reasons, far too large motors are undesirable. In this country, stationary cranes are mostly electrically operated, while travelling cranes are operated by means of internal combustion engines, or by hand.

This paper deals with fluctuations of output due to the influence of local climatic factors on cranes used in the different regions of the country.

## INFLUENCE OF CLIMATIC FACTORS ON INTERNAL COMBUSTION ENGINE POWER

The maximum indicated power of an internal combustion engine is mainly dependent, for a constant speed, on the quantity of combustion air in the cylinders. This quantity and the thermal and mechanical efficiency of the engine are, in turn, dependent on atmospheric conditions. The calculation of the useful power with these factors taken into consideration is extremely complicated and would still leave out such factors as the structure, process of regulation, and condition of the engine.

For this purpose, equations have been formulated for reducing the indicated power, measured under prevailing conditions, to standard conditions of temperature and pressure. The first assumption was direct proportionality to air density.

$$\frac{P}{P_0} = \frac{p}{p_0} \cdot \frac{T_0}{T} \quad (1)$$

For a closer approximation, humidity and changes due to the process of injection are taken into consideration:

$$\frac{P}{P_0} = \frac{p - \varphi w}{p_0 - \varphi_0 w_0} \sqrt{\frac{T_0}{T}} \quad (2)$$

In a research report<sup>1</sup> published in 1933, the author showed that the theoretical power calculated for different temperatures lies between the values given by the above two equations. On the basis of extensive experiments, a more exact relationship was formulated recently, with the influence of the state of the air on the mechanical efficiency and all important meteorological factors (excluding the minor effects of wind, clouds, radiation etc.) taken into consideration.

$$\frac{P}{P_0} = 1.124 \frac{p - \varphi w}{p_0 - \varphi_0 w_0} \left( \frac{T_0}{T} \right)^{3/4} - 0.124 \quad (3)$$

Eq. (3) is based on a mechanical efficiency of 0.85 under standard conditions.

#### STANDARD STATE OF THE AIR

The standard state is defined to correspond to the rate power. The maximum output for short operations is also referred to this standard.

Table I shows the various definitions of the standard state<sup>2</sup>. For engineering purposes, the values denoted by the zero-subscript are used.

TABLE I  
Standard air data

	Pressure (torr.)	Temperature (°C)	Relative humidity (%)	Motor power (%)
Atmosphere (techn.)	$p_0 = 736$	$t_0 = 20$	$\varphi_0 = 60$	100
Atmosphere (phys.) BS 649; 1949	760	0	0	112
British Standard for Internal Combustion Engines	749	29.4	50	100
PTC 17—1949 ASME	760	20	0	105
Internal Combustion Engines Commission Internationale de Navigation Aérienne	760	15	0	107
Annual average, Jerusalem	689	17.1	62	94
Annual average, Tel-Aviv	759	19.1	69	104

The following equation is obtained by substituting the standard numerical values in Eq. (3), and serves as basis for the following sections (Figure 1):

$$100 \frac{P}{P_0} = 10.97 \frac{p - \varphi w}{T^{3/4}} - 12.4 \quad (4)$$



INTERNAL COMBUSTION ENGINE OUTPUT IN ISRAEL

Using annual averages of meteorological observation data<sup>3</sup>, the author calculated, with the aid of Eq. (4), motor outputs for the various regions of the country. The results are shown in the chart (Figure 2) in the form of lines of equal output. The chart emphasizes the far greater importance of barometric pressure (dependent, in turn, on altitude of location), as a governing factor, compared with temperature. For example, the high barometric pressure in the Jordan valley and the region south of the Dead Sea causes increased outputs, in spite of the high temperature. Low humidity is an additional cause of increased output. Because of the uneven distribution of observation posts over the country, regional boundaries had, in some cases, to be determined by extrapolation. The estimated mean error of the map is  $\pm 1\%$ .

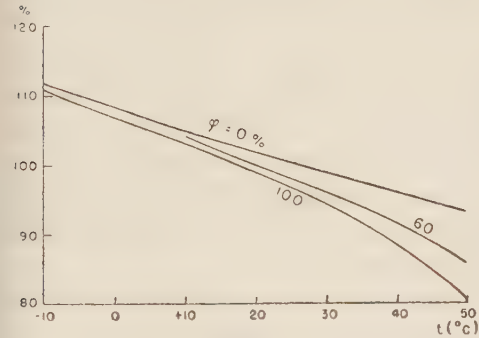


Figure 1  
Internal combustion engine output, percent of standard. (Barometric pressure = 736 torr.;  $t$  = air temp.;  $\varphi$  = relative humidity).



Figure 2  
Annual regional averages of internal combustion engine output in Israel. (Standard 100% at 736 torr., 20°C and 60% relative humidity).

On the other hand, local fluctuations of output throughout the year are mainly due to fluctuations of temperature, the effect of those of pressure being considerably more limited. Decreases are observed, for instance, on summer afternoons (characterized by hot and humid weather) and increases — on winter mornings (cold and dry weather).

The overall annual average for the country is 101%. Common local deviations are  $\pm 5\%$ , and in extreme cases as high as  $\pm 10\%$ . Mobile equipment shifted over the country under extreme climatic conditions may show, for short periods, fluctuations of  $\pm 15\%$ .

#### INFLUENCE OF CLIMATIC FACTORS ON HAND OPERATOR'S OUTPUT

The problem of the operator's output in the case of hand-operated equipment (under normal climatic conditions) was studied by means of psychotechnic tests<sup>4</sup> which provided data on the optimum dimensions of the crank device and the conversion efficiency of the chemical energy of the human organism into mechanical energy.

The optimum dimensions are as follows: elevation of crank axis above floor level = 1.0 m, radius of crank = 0.3 m, force to be applied by operator = 12 kg.

The I.L.O. code specifies<sup>5</sup>, for the rated load, a maximum force of 10 kg, while the British Standard Specification is based on an output of 0.11 HP and the Swiss code specifies a maximum force of 25 kg.

The operator's output is obviously dependent on a large number of factors, such as physique, nutrition, clothing, morale, compensation etc., and the biological effects of the climate vary according to origin — e.g. for immigrants from North Africa compared with those from the Northern countries. The functional relationship is thus far more difficult to determine than in the case of motor operated equipment. Using experimental data quoted in literature, the author has attempted to formulate this relationship as shown in the diagram, Figure 3, assuming a constant output of 100% up to the standard effective temperature ( $18.3^{\circ}\text{C}$ ) and a subsequent decrease of 5% per degree. The diagram has been found to represent the actual picture fairly closely for the effective temperature range of  $15$ — $24^{\circ}\text{C}$  (measured by the wet-and-dry bulb method). The effects of wind and radiation, mutually counteractive in certain respects, were again neglected in this case.

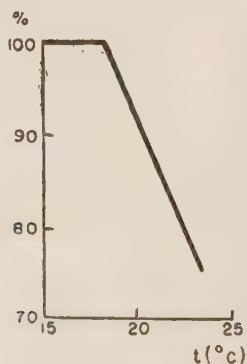


Figure 3  
Hand operator's output at  
different effective temperatures.

HAND OPERATOR'S OUTPUT IN ISRAEL

The chart (Figure 4) was drawn up on the same principles as that in Figure 2. Together with Table II it shows that, compared with an output of 100% in cool regions (where the effective temperature does not exceed 18.3°C), the average annual output in the Dead Sea region is 80%. In hot and humid weather, output decreases and in extreme cases complete inactivity may result. (It should be noted that maximum temperature in most of the regions of the country is over 40°C, and in certain cases over 50°C).



Figure 4  
Annual regional averages of hand operator's output in Israel.



TABLE II  
Annual average outputs (percent of standard) at meteorological observation posts marked on chart, Figure 4

Locality	Internal combustion engines (Eq. 4)	Hand operator (diagram, Figure 3)
Jerusalem	94	100
Tel-Aviv	104	100
Haifa (Mt. Carmel)	100	100
Mt. Canaan	94	100
Tiberias	105	88
Beersheba	99	100
South Dead Sea	107	80
Eilat	102	85

The estimated mean error of the chart is  $\pm 5\%$  — considerably lower than for that in Figure 2, as the diagram in Figure 3 is an approximation, and due to the fact that no temperature data were available for the Southern Negev, a region of decisive significance in this case. The overall annual average figure for the country is 95%.

#### NOTATION

$P$  = output

$p$  = barometric pressure (torr.)

$w$  = partial pressure of water vapour (torr.)

$t$  = temperature ( $^{\circ}\text{C}$ )

$T$  = absolute temperature ( $^{\circ}\text{K}$ )

$\varphi$  = relative humidity

Zero subscript refers to standard.

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# STUDY ON NEW AND REGENERATED MOTOR OILS

A. B. STERN

*Supply Department, Ministry of Defense*

## ABSTRACT

New and regenerated motor crankcase oils were compared by conventional test methods, constitutional analysis (n-d-M) and engine performance tests. New and regenerated oils were used in engines which were afterwards stripped and examined. No fundamental difference could be detected in oil or engine performance characteristics. Properly regenerated lubrication oils blended with suitable additives have given satisfactory results as motor lubricants.

## INTRODUCTION

This study was carried out in an attempt to investigate the possibility of using regenerated oils for motor engine lubrication, as to the best of our knowledge no similar work on this subject has been published. For this reason, new and regenerated oils were compared before and after use in engines.

The following facts on lubricating oils and additives may serve to introduce the problem involved in this study.

### *Composition of lubricating oils*

Lubricating oils contain most complex hydrocarbon molecules. These hydrocarbons may contain from 20 to 70 or more carbon atoms per molecule, with molecular weights varying from 250 to 1000 or more. Knowledge of composition is very limited due to the enormous variation of isomer structures and complexities of the molecules.

Petroleum hydrocarbons may be classified according to their structures into paraffins, naphthenes, olefins and aromatics. These components may occur individually, condensed or combined, comprising one ring or more with paraffinic side chains. The combination of these components appears to determine the oil's characteristics. For example, naphthenes having a large number of rings per molecule with paraffinic side chains or short length have lower viscosity indices than rings with long side chains<sup>1</sup>.

Lubricating oils are prepared to specifications, the U.S. Military specifications being normally employed for heavy duty oils. In order to fulfill these requirements, crankcase lubricants are "doped" with suitable additives, which impart to the oil superior anti-oxidant and detergent properties. Oils are required to undergo special engine performance tests and they are pronounced suitable only after passing these tests. For the purpose of our research two different types of heavy duty oils were studied, one of the

2104-B grade and the other passing MIL-0-2104 requirements<sup>2</sup>. The latter possesses a higher detergency level and has normally a much higher additive content.

### *Used lubricating oils*

Used crankcase oils<sup>3</sup> are contaminated by oil-soluble and oil-insoluble substances, these contaminants being divided roughly as follows:

*Intrinsic contaminants.* Intrinsic contamination arises from the deterioration of the oil itself within the crankcase oil system and consists in the main of oxidized products of the lubricants, and of soluble and insoluble additive depletion products. Polymerization of the primary oxidation products may occur, and if the oxidation is severe this may lead to deposit formation. In general, however, oil oxidation products remain soluble and the direct formation of insolubles by oil oxidation occurs mainly with low viscosity index oils under high temperature conditions. The rate of formation and the properties of these contaminants are naturally dependent to a great extent upon the quality of the lubricant and design of the engine.

*Extraneous contaminants.* Extraneous contamination is caused by incomplete fuel combustion, by engine wear and by the absorption of deleterious foreign matter in the oil, via the air intake. These are fuel soot, unconsumed fuel, water, dust, metal particles, etc.

There are also contaminants which arise from interaction between fuel and oil and may contain oil oxidation particles. Much has been written about the nature of oxidized oil<sup>1</sup>. Paraffinic base oils usually have higher acidity formation but lower sludging tendency than naphthenic-asphaltic base oils. Final oxidation products are mainly hydroxy acids.

### *Regeneration processes and analysis*

The volatile contaminants in used oils may be removed either by steam or vacuum distillation with the help of a tube furnace and fractionating column, or a pot still.

The solid contaminants such as carbonaceous, asphaltic and colouring matter in used oils may be removed by treatment with Fuller's earth or by washing with  $H_2SO_4$  followed by neutralization and/or Fuller's earth treatment. Either of these two processes may be preceded by some sort of alkali wash to remove the larger non-colloidal solid contaminants. In most processes it is usual to combine the earth treatment with the distillation<sup>1</sup>.

### *Methods of analysis*

A variety of physical and chemical tests are known, whereby certain properties of motor oils may be evaluated. These tests are standardized and detailed, e.g., in the Standard Methods of the American Society for Testing Materials<sup>5</sup> or the Institute of Petroleum<sup>4</sup>.

The most important properties are viscosity, viscosity index, flash point, acidity, ash content, carbon residue and others.



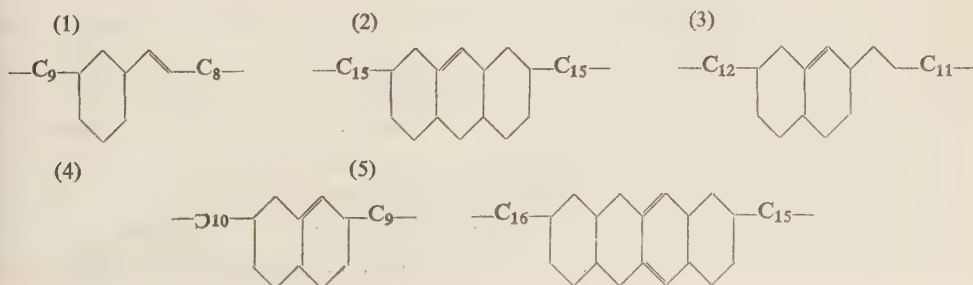
In addition to the other conventional tests, a new test method — the so-called n-d-M method<sup>6</sup> — was introduced, in order to examine the structural properties of lubricating oils. The significance of constitutional or structural group analysis is based on the insight into the chemical composition of mineral oils which it provides. The basic data required for the group analysis are density, refractive index and molecular weight, consequently this method is known as the n-d-M method. The n-d-M method has certain limitations but presents a convenient and simple means for estimating the distribution of carbon atoms in the oil in terms of aromatic rings, naphthenic rings and paraffinic chains. The group analysis provides the means of determining the statistical distribution of these structural elements in the oil. This method proved conclusively that all mineral oils, even after the most exhaustive refining, contain ring structures. For example, as can be seen in Table I, medicinal white oil is far from being a mixture of paraffins only, and although this oil is almost aromatic free, it does contain naphthenic constituents<sup>7</sup>.

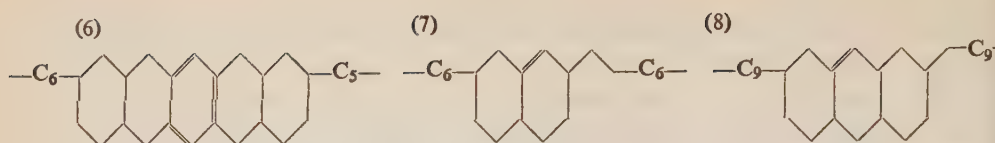
TABLE I

Grade of oil	Viscosity data à 210° F cst V.I.		MW	K	Carbon distribution			
					%C <sub>A</sub>	%C <sub>N</sub>	%C <sub>P</sub>	%C <sub>R</sub>
White oil	3.5	106	355	12.5	1	30	69	31
Aviation HVI	22.0	105	615	12.4	6	27	67	33
MT SAE 30 HVI	11.8	97	490	12.4	5	28	67	33
Turbine	7.0	115	410	12.4	3	31	66	34
Gear SAE 140 HVI	36.2	96	680	12.4	7	30	63	37
Gear SAE 140 LVI	26.0	—16	455	11.5	14	52	34	66
Refrigerating	4.9	56	355	11.6	17	35	48	52
MVI oil	11.0	64	460	11.9	5	41	54	46

As could be expected, the high V.I. oils contain a smaller proportion of rings than medium V.I. oils and low V.I. oils, the %C<sub>R</sub> being roughly 30% for the 100 V.I. and about 70% for the lowest V.I. oils. It is also interesting to note that high V.I. solvent refined oils show very little variation in carbon distribution, even when these oils have been prepared from crudes of different origins.

The following structural formulae illustrate the oils mentioned in Table I and are based on the n-d-M method, and will demonstrate the constitutional difference between the various types of mineral oils. For simplicity, two paraffinic side chains attached to condensed rings were assumed:





### *Inhibitor and detergent additives*

The purpose of motor oil additives is to improve the properties of refined mineral lubricating oils to protect them against excessive oxidation and deposit formation in engine use. Much research has been carried out on oxidation mechanisms and it has been conclusively proved that all the hydrocarbons present are liable to oxidize, the final products being of an acidic or complex oxy-polymer nature, resembling resins and asphaltic matter<sup>1</sup>. Comparing paraffins, naphthenes and aromatics, the latter hydrocarbons are most susceptible to oxidation. Modern solvent extraction plus the use of additives minimizes the formation of these undesirable constituents, and, apart from these obvious advantages, suitable additives have also proved an excellent medium for the reduction of varnish formation and carbonaceous deposits on piston skirts, ring grooves, valve stems, etc.

Marked differences exist in the susceptibility of various base oils to additives, depending largely upon the origin of oil, the degree of refinement, etc.

The function of detergent additives is to impart properties to the motor oil which will enable it to keep oxidation products, insoluble matter and other contaminants in suspension. They are nearly all dark in colour and possess a characteristic odour easily discernible in "doped" oil.

## NEW AND REGENERATED MOTOR OILS

### *Experimental procedure*

The main purpose of this investigation was to examine and compare new and regenerated crankcase oils.

New oils were branded products of known oil companies. After use these oils were regenerated. The bulk of used oil was treated in an industrial plant by a combined earth and distillation process; small samples were similarly treated in the laboratory (Table III).

For the purpose of this investigation several Ford trucks of the F-1 type equipped with 6 cylinders, 4 stroke, side valve engines operating on 70 octane gasoline<sup>2</sup> were used. Since the purpose of this test was to obtain average samples of the oil under normal working conditions, the vehicles chosen, though not new, were in good condition.

The series of tests were carried out in both the Northern and Southern districts of the country, several new and regenerated oils being used in order to obtain a fair and representative performance result. The oil was "topped up" in some cases during the running of the cars and records were carefully kept. The series was run on 2000 and

3000 km oil changes, after which time the oil was drained from the engines and submitted to the laboratory for testing.

Apart from the opportunity of comparing results after using new and regenerated oils, the different oil change periods also served as a means of studying the changes of properties of the regenerated oil and, to a lesser degree, the contamination of the oil which appeared to vary according to the various working conditions. This research was carried out during the years 1951 to 1953.

In the introduction it has been shown that Heavy Duty Oils (HD) are made of straight mineral base oils and additives.

The following Table II illustrates the properties of the base oil (B) and the "doped" oil (H.D.). It will be noted that the principal differences are in ash content and carbon residue. The influence on performance of "doped" and natural oils will be discussed later but the effectiveness of additives is invariably proven by standard performance engine tests.

TABLE II

Oil	B.11	MIL-O-2104 H.D.11 (Additive A)	B.14	MIL-O-2104 H.D.14 (additive B)
Specific gravity à 60°F	.890	.892	.891	.896
Viscosity à 100°F cst	158.76	156.4	169.4	162.2
Viscosity à 210°F cst	14.33	14.38	14.72	14.0
Total acidity	.08	.50	.014	1.06
Inorganic acidity	neutral	alkaline	neutral	alkaline
Ash content %	nil	1.1	nil	1.06
Carbon residue %	0.32	0.91	0.23	1.43
Colour	5	6	4.5	5.5
Oxidation stability: I.P. 48/44				
Viscosity ratio	1.5	1.1	1.3	1.2
Carbon increase %	.82	.41	.29	.15

### *Treatment of new and used oils in plant and laboratory*

Extensive laboratory tests were carried out on plant and on laboratory regenerated oils and good correlation of results was found. The drain samples before treatment are described as "used oil" and the treated ones as "regenerated oil" (see Table III).

TABLE III

### *Comparison between plant and laboratory treatment of used oil*

Type of treated oil	Oil C (Plant)	Oil C (Laboratory)	Oil B-966 (Plant)	Oil B-966 (Laboratory)
Specific gravity à 60°F	.8885	.8883	.886	.885
Flash point °F	445	430	465	435
Colour	3.5	3	3.5	2.5/3
Ash content %	.005	nil	nil	nil
Viscosity à 100°F cst	120.5	115.5	160.5	162.0
Viscosity à 210°F cst	12.1	11.8	14.3	14.6
Viscosity increase	1.36	1.43	—	—



Table IV which follows illustrates the typical constitutional analysis of new and regenerated motor oils which were employed during the period of this research. The original oils were all solvent refined, high viscosity index lubricating oils which were doped by suitable additives.

The new oils were known branded products supplied by various companies and the regenerated oils were obtained from a mixture of these oils after use. No great variations in composition were noticed.

TABLE IV  
*Constitution of typical new and regenerated base oils*

Oil No.	MT.30	New oil M.1	M.3	B.5	Regenerated oil			
					B.6	B.10	B.11	B.14
% C <sub>A</sub>	5	5	6	8	8	9	8	5
R <sub>A</sub>	—	.3	.4	.5	.5	.6	.5	.3
% C <sub>N</sub>	28	28	27	28	28	24	26	31
R <sub>N</sub>	—	2.4	2.4	2.3	2.4	2.1	2.4	2.8
% C <sub>P</sub>	67	67	67	64	64	66	66	67
R <sub>T</sub>	—	2.7	2.8	2.8	2.9	2.7	2.9	3.1
% C <sub>R</sub>	33	33	33	36	36	33	34	36
K-factor	12.4	12.4	12.4	12.4	12.3	12.3	12.3	12.4

Table V shows results of repeated regenerations of a base oil (B-16), so as to examine the gradual change in constitutional and other properties.

Base oil B-16 was subjected to a treatment resulting in oil B-16/1, which in turn was treated to give oil B-16/2.

The oils changed slightly on treatment, aromaticity decreased and paraffinicity increased. This change is reflected in other physical properties too, such as the viscosity index and K-factor, which was calculated according to a monogramme based on specific gravity viscosity relation<sup>12</sup>.

TABLE V  
*Repeated treatment of regenerated base oil B-16 which was twice re-treated in the laboratory*

	B-16	B-16/1	B-16/2
Specific gravity à 60° F	0.8881	0.8867	0.8834
Viscosity à 100° F cst	169.9	177.9	172.7
Viscosity à 210° F cst	14.85	15.43	15.53
Colour	4/4½	2	2
Viscosity index	+94	+95	+99
Mean molecular weight	550	565	570
K-factor	12.40	12.45	12.50
% C <sub>A</sub>	7.0	5.5	5.0
R <sub>A</sub>	0.4	0.3	0.3
% C <sub>N</sub>	27.0	27.0	27.0
R <sub>N</sub>	2.60	2.65	2.55
% C <sub>P</sub>	66.0	66.5	68.0
R <sub>T</sub>	3.0	2.95	2.85
% C <sub>R</sub>	34.0	33.5	32.0

*Comparison of new and regenerated oils, 2104-B specification*

As mentioned in the introduction, lubricating oil becomes contaminated during use by indigenous and extraneous matter which can be determined and roughly classified by analysis. The following Table VI compares new and used oils, the new oil being an SAE 30 which conforms to 2104-B specification and the used oil being doped after regeneration to meet the same specification. Base oil B-6 is regenerated used H.D.-SAE 30 oil, and regenerated H.D.-6 is an oil twice used and twice regenerated which retains well the main characteristics of the original oil. The oils were run for approximately 1500 km.

TABLE VI

Oil No.	New oil series 2104-B-level		Regenerated oil series 2104-B-level			
	New H.D. SAE-30	Used H.D. SAE-30	Base oil B-6	H.D.6	Used H.D.6	Regenerated H.D.6
Spec. gravity à 60°F	.890	.889	.891	.891	.899	.888
Viscosity 100°F cst	122.3	95.5	127.4	126.8	112.6	123.7
Viscosity 210°F cst	12.0	10.45	12.3	12.2	11.9	12.2
Viscosity index	95	100	94	94	98	96
Flash point °F	440	170	430	425	180	455
Total acidity	.02	.025	.02	.002	.03	.01
Ash content %	.63	.86	.01	.4	.65	nil
Carbon residue %	.90	1.38	.25	.51	1.64	.31
Asphaltenes %	nil	.098	nil	nil	.16	nil
Oxidation stability:						
Viscosity increase	1.38	—	1.36	1.34	—	1.40
Carbon increase %	.89	—	.93	.90	—	.79
Ba-content %	—	—	—	2.15	2.14	—
K-factor	12.3	—	12.3	12.3	—	12.4

The used oils were filtered through a Whatman No. 5 filter paper before the tests were carried out.

The results tabulated above show a great similarity between the new oil and regenerated oil series.

On examining the properties of the unused oils (new H.D. SAE-30 and H.D. 6), it may be seen that viscosities conform to the SAE 30 grade, flash points are high, ash and carbon residue comparatively high due to the additives. Asphaltenes are not present and oxidation characteristics are well within limits.

When these oils were examined after use, it was observed that they were dark in appearance and had an odour of burnt fuel, as is normal with all used oils. The viscosities were lower than they were before use, due to dilution with fuel components. This effect was noted again in the low flash point. The total acidity was increased during use, and the higher ash content indicates inorganic impurities. Oxidation products in the used oil account for increases in the carbon residue and asphaltene values.

The regenerated Base Oils (B-6 and regenerated H.D. 6) are indistinguishable from normal new base stocks. The specific gravity is somewhat lower than in the original unused oil, but viscosities and flash point have returned to their original values. The oil is free from ash and asphaltenes.

Further figures concerning the constitution of these oils may be seen in Table IV, where it will be again noted that new and regenerated oils have similar constitutional properties.

The following analysis illustrates, in another test series of the same type of oils as previously used, the impurities in the used oil and the oil properties after treatment. In addition to the asphaltenes, the benzene insolubles were also determined, the A.S.T.M. method<sup>5</sup> D.893—46 for normal pentane and benzene insolubles, modified and pentane replaced by S.B.P.-Benzin 60/90 being used. A soxhlet extraction was also applied. The main purpose of this test was to indicate the difference in resins in the used and refined oils, since in new oils the resins were absent. (Resins = S.B.P. insolubles — Benzene insolubles).

TABLE VII  
*Analysis of used and regenerated oils—2104-B specification*

Oil	Used oil No. 6 a	Regenerated oil No. 6 a	Used oil 2440	Regenerated oil 2440
Specific gravity	.884	.878	.892	.881
Ash content %	.32	nil	.49	nil
Carbon residue %	1.72	.12	1.38	.17
Asphaltenes %	.29	nil	.10	nil
Benzene insolubles %	.28	nil	.05	nil
Resins %	.01	nil	.05	nil

These tests show that the regeneration process employed is highly efficient and removes ash, polymerization products and other impurities.

It may be concluded that luboils of the 2104-B level were successfully treated, a good base oil was received which, blended with H.D.-additives, gave a satisfactory H.D.-oil.

#### *Comparison of new and regenerated oils, MIL-0-2104 specification*

The next step was to study MIL-0-2104 specification oil under similar conditions and for these tests it was again decided to use a Ford F-1 vehicle. The capacity of the crank-case of its engine is approximately 4.5 kg. Before starting the test the engine was thoroughly flushed and cleaned and during the experiment the oil was "topped up" as required. Approximately 1 kg of oil per 1000 km was consumed. Two series of tests were run separately, in the first case the oil being withdrawn after 2000 km and in the second case after 3000 km for both the new and regenerated oils. The average test took from three to five weeks to complete. The following Table VIII shows the analysis of the new oil, containing additives. Obviously the additive changes the oil



properties of the base oil in respect of specific gravity, ash content, etc., and this change must be taken into consideration. Therefore, for comparison with regenerated oil the additives must be removed from the new H.D.-30 oil, which for comparison was therefore submitted to the same treatment as the used oil.

Table VIII gives the full physical and chemical analysis of the different oils. It should be borne in mind that properties of the corresponding oils only may be compared for evaluation.

*Glossary to Table VIII*

MIL-1 Original H.D.-30

Treated original H.D. 30

H.D.-30 after 2000 km

H.D.-30 after 3000 km

MIL-2

H.D.-11

Base B-11

H.D.-11 after 2000 km

H.D.-11 after 3000 km

unused H.D.-oil after treatment, additive free

H.D.-oil after 2000 km use and treatment

H.D.-oil after 3000 km use and treatment

regenerated oil B-11, blended with additives

regenerated oil, base oil

H.D.-11 oil after 2000 km use and treatment

H.D.-11 oil after 3000 km use and treatment

TABLE VIII

	MIL-1 <i>New oil series</i>					MIL-2 <i>Regenerated oil series</i>		
	Original H.D.30	Treated original H.D.30	Treated after 2000 km	Treated after 3000 km	H.D.-11	Base B-11	Treated after 2000 km	Treated after 3000 km
Colour	4/4½	1/1½	1½/2	2/2½	5/5½	4/4½	2/2½	2½/3
Spec. grav. à 60°F	.888	.884	.883	.883	.891	.890	.887	.888
Vis. à 100°F cst	123.4	116.5	133.7	106.9	156.4	158.8	165.5	181.5
Vis. à 210°F cst	12.15	11.85	13.25	11.28	14.4	14.2	14.5	15.5
Viscosity index	96	98	100	99	97	94	93	94
Ash content %	.63	.004	nil	nil	nil	nil	traces	traces
K-factor	12.3	12.4	12.5	12.4	12.3	12.3	12.4	12.4
Mean molecular weight	505	520	545	520	535	540	565	555
% C <sub>A</sub>	1	5	4	3	7	8	6	6
R <sub>A</sub>	0	.3	.3	.2	.5	.5	.4	.4
% C <sub>N</sub>	39	28	29	32	28	26	26	28
R <sub>N</sub>	2.7	2.4	2.5	2.6	2.4	2.4	2.5	2.5
% C <sub>P</sub>	61	67	67	65	65	66	68	66
R <sub>T</sub>	3.2	2.7	2.8	2.8	2.8	2.9	2.9	2.9
% C <sub>R</sub>	39	33	33	35	35	34	32	34

The following conclusions may be drawn from the above mentioned results: The general behaviour of these two series (MIL-1 and MIL-2) is similar to that of the 2-104B oils in the tests previously described. On prolonged use the colour of the oil darkens but is restored by regeneration. The doped oils have higher specific gravities due to the higher gravity of the additives. In general specific gravities of regenerated used oils are somewhat lower than those of the original oils.

Viscosities for the MIL-1 oil show first an increase (2000 km) and a decrease on longer use. For the MIL-2 oil the viscosities increase in use.

The K-factor does not change appreciably.

Molecular weight tends to increase in use but for both oils reaches a peak on the 2000 km sample, which may indicate that at first lighter portions of the oil burn away or that polymerization reactions set in.

In respect of group analysis, additives obviously distort the values obtained for the functional groups and for this reason the n-d-M method cannot be applied. Series MIL-1 and MIL-2 in use, show a tendency for the  $\%C_A$  and the  $R_A$  contents to decrease, which may be due to changes in the less stable aromatic portions. Generally no fundamental differences exist between series MIL-1 and MIL-2.

Engines using new H.D. oils and doped regenerated H.D. oils were stripped and examined. Both new and regenerated oils gave satisfactory results, in respect of visual observations such as lacquering and sludge deposits. Engine wear and bearing corrosion were no worse for regenerated oils than for new H.D. oils. It may be concluded from the above considerations that new H.D. oils and doped regenerated oils possess approximately the same stability and undergo the same changes when used in engines. This conclusion will be further supported in the chapter on engine performance tests.

#### ENGINE PERFORMANCE TESTS ON MOTOR OILS

It is generally agreed that the only satisfactory means of evaluating the performance characteristics of motor oils is by actual use in engines. Many engine tests have been tried out but only few have survived. The most widely used tests and those required by the U.S. Army Ordinance specification for H.D.-oils are the L-4 Chevrolet test and the L-1 Caterpillar test, AXS-1554 and AXS-1551 specifications respectively<sup>2,10</sup>.

The L-4 test is roughly equivalent to the operation of a car at sixty miles per hour continuously running for thirty-six hours (i.e. 2160 miles), under purposely selected severe conditions. The L-1 test may be considered equivalent to the operation of a four-stroke engine (C.I.) for a period of 480 hours under severe conditions. These engine tests determine the oxidation, bearing corrosion and detergency characteristics of engine crankcase oils designed for use under heavy duty service conditions. The tests are expensive to carry out and require a high standard of skill to perform.

After careful research and study of literature and other informants on the subject, it was concluded that Towle's research on the A.V. 1 Petter Engine<sup>8</sup> would serve well as a means of classifying an oil as "Pass", "Near-pass" or "Fail", and although this method of test is much simplified and far less expensive to carry out than the two others mentioned, it has proved satisfactory. This method of test is carried out in a single cylinder four-stroke high speed diesel engine which is run under standard controlled conditions, the equivalent of many thousands of miles running being obtained in the comparatively short period of the 120-hour test. On completion of the test the engine is stripped, examined and rated.

Towle has shown that the results achieved on the A.V. 1 Petter engine compare very favourably with actual service performance and the Towle paper shows how the engine can be used to predict the performance of oils on the Caterpillar L-1 test with a reasonably fair degree of certainty. Proof that this view is shared by others lies in the increasing adoption of this engine as screening oil test unit by laboratories both in the United Kingdom and other countries<sup>9</sup>.

For checking the suitability of regenerated motor oils the following procedure was adopted. The regenerated base oil was carefully tested for its physical and chemical properties. After the base oil had passed these tests, it was sent to a recognized laboratory where it was engine tested after blending with suitable H.D.-additives. According to performance test results the correct amounts of inhibitor and detergent additives were blended into the base oil, and Tables IX and X show the best results on the L-4 test engine and the A.V.1 Petter engine. In Table IX different oils are compared, the oils being L.D., an oil of low quality, H.D., an oil of good quality and H.D.-R, a locally regenerated oil "doped" to pass MIL-0-2104 specification requirements.

TABLE IX

*L-4 engine tests on low V.I., high V.I. and regenerated motor oils*

(Engine cleanliness rating: 10 — perfect, 0 — very bad)

	L-D LVI	H.D. LVI HVI	H.D.-R regenerated H.D. oil	Specific requirements
<i>Varnish deposits</i>				
Piston skirts	3.0	9.5	9.8	
Rocker arm cover plate	6.0	10.0	10.0	
Push rod cover plate	6.0	9.5	10.0	
Cylinder walls	7.0	10.0	10.0	
Crankcase oil pan	7.0	10.0	9.0	
Total varnishing rating	29.0	49.0	48.8	Minimum 40
<i>Sludge deposits</i>				
Rocker arm assembly	7.0	9.5	9.5	
Rocker arm cover plate	7.0	10.0	9.5	
Push rod cover plate	5.0	9.5	9.0	
Oil screen	8.0	10.0	9.5	
Crankcase oil pan	7.0	10.0	9.0	
Total sludge rating	34.0	49.0	46.5	Minimum 45
Total varnish & sludge rating	63.0	98.0	95.3	Minimum 87.5
Bearing corrosion, average loss (g)	0.05	0.07	0.036	Maximum 0.125
<i>Oil drain analysis</i>				
% Viscosity increase at 100°F	120	60	12.1	
Acidity number	0.3	0.5	0.56	
Pentane insolubles %	2.6	0.8	0.63	
Benzene insolubles %	0.7	0.7	0.60	
Resins %	1.9	0.1	0.03	
Carbon residue %	2.6	2.6	3.38	



Thus it will be seen that the regenerated H.D. oil passed satisfactorily the L-4 test and in addition it also passed satisfactorily the L-1 Caterpillar test.

Table X shows two regenerated base oils which were doped to the MIL-0-2104 specification level and tested on the A.V.1 Petter engine.

It is apparent that both oils reached nearly the possible maximum rating and also later proved satisfactory in actual use.

TABLE X  
*Petter A. V. 1 engine test on regenerated H.D.-oils*

Oil No.	H.D.-11	H.D.-14	Maximum possible rating
Crown cutting rating	4.2	4.4	5.0
Piston ring sticking	35	35	35
General component deposits	8.6	9.2	10
Scraper ring sludge deposits	10	10	10
Piston land lacquer deposits	3.2	7.7	10
Piston skirt lacquer deposits	28.0	29.9	30.0
Total merit rating	89.0	96.2	100
Total deposit rating	49.8	56.8	60
Top compression ring weight loss (mg)	82	53.5	40—110
Top groove carbon deposit rating	9.0	6.2	10
Piston skirt deposit rating	28.2	29.9	30
Cylinder liner lacquer deposit rating	10.0	10.0	10.0

In addition to the performance tests, the engines were inspected after the use of H.D. oils, 2104-B, MIL-0-2104 new and regenerated oils in a central repair workshop. These engines were stripped and examined for cleanliness, various deposits, bearing conditions, etc., and while it was not possible to establish the actual running period of the engines, it may be assumed that on the average most engines were repaired at similar mileage intervals.

Pistons were rated with the aid of the photographs shown in Figure 23, "A.V.1 Piston after 120 hour test, average results on various types of oils and fuels", Journal of the Institute of Petroleum<sup>8</sup>. The results proved that the average engine, running on oils of the MIL-0-2104 specification level, corresponded to the respective photograph of the same type of oils, and whereas the previously used 2104-B type oils have shown greater deposit formation in the engines, it was obvious that the new or regenerated oils corresponding to the higher MIL-0-2104 level were better in performance.

#### CONCLUSION

This study has shown that, when used Heavy Duty motor crankcase oils are properly regenerated and doped by suitable H.D. additives, they give satisfactory performance.

Extensive laboratory testing of physical and chemical properties has shown a great similarity between new and regenerated oils.

The new n-d-M method for constitution analysis was successfully applied to compare new and regenerated oils, which showed great similarity. Further, this method has given considerable information on the constitution of different types of undoped new oils, and the effects of regeneration on their constituents. These effects are principally, reduction in the aromatic content, with a corresponding increase in viscosity index. Performance engine tests L-1 Caterpillar, L-4 Chevrolet and A.V.1 Petter, have shown that doped regenerated motor oils are equal in quality and performance to new oils. Regenerated oils of the MIL-0-2104 specification level have proved entirely satisfactory in driving practice of two years' experience. Further, upon stripping engines have shown similar deposit formation after having been run on either new or regenerated I.D. motor oils.

## SYMBOLS AND TEST METHODS

MT oils	=	Motor transport oils
I.D. oils	=	Heavy duty motor oils
IP	=	Institute of Petroleum
ASTM	=	American Society for Testing Materials
VI	=	Viscosity index
LVI	=	Low viscosity index
HVI	=	High viscosity index
K or K-factor	=	U.O.P. characterization factor
	=	Refractivity index of sodium D Line
	=	Density
M or MW	=	Average molecular weight
$t_T$	=	Total number of rings per mean molecule
$t_A$	=	Number of aromatic rings per mean molecule
$t_N$	=	Number of naphthenic rings per mean molecule
% C <sub>R</sub>	=	Number of carbon atoms in ring structure per 100 carbon atoms per sample (percentage of carbon atoms in ring structure)
% C <sub>A</sub>	=	Number of carbon atoms in aromatic ring structure per 100 carbon atoms per sample
% C <sub>N</sub>	=	Number of carbon atoms in naphthenic ring structure per 100 carbon atoms in sample
% C <sub>P</sub>	=	Number of carbon atoms not in ring structure per 100 carbon atoms in sample
% C	=	Percentage by weight of carbon present
% H	=	Percentage by weight of hydrogen present

*Test Methods Employed:*

Specific gravity/density	: I.P. 594
Colour	: Modified Union ASTM D-1555
Flash point	: I.P. 34
Viscosity	: I.P. 71
Viscosity index	: I.P. 73
Acidity, acid number	: I.P. 1
Inorganic acidity	: I.P. 1
Ash content	: I.P. 4
Carbon residue	: Ramsbottom method I.P. 14
Oxidation test for lubricating oils	: I.P. 48
K-factor	: W. L. Nelson <sup>12</sup>
Asphaltenes in oils	: I.P. 6
Normal pentane and benzene insolubles	: ASTM D-893
Barium in lubricating oils	: I.P. 110
Refractivity index	: Abbé apparatus I.P. 60
Mean molecular weight	: Mills <sup>11</sup> , Hirschler <sup>13</sup>

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# POLAROGRAPHIC DETERMINATION OF TRACE ELEMENTS IN MANGANESE METAL AND SALT SOLUTIONS

## I. SIMULTANEOUS DETERMINATION OF TRACES OF COPPER, CADMIUM, NICKEL AND ZINC

Y. ISRAEL

*Israel Mining & Industries Laboratories, Haifa*

### ABSTRACT

A method was developed for the simultaneous determination of traces of copper, cadmium, nickel and zinc in electrolytic manganese metal and salt solutions in a 1 M ammonium chloride + 1 M ammonium hydroxide supporting electrolyte. The base solution also contained 5% of ammonium sulphate to eliminate the interference of lead on the copper wave, 0.01% gelatin as maxima suppressor and 2% sodium sulphite to eliminate the effect of dissolved oxygen.

Standardized procedures for the preparation of test samples and blanks, as developed in this work, proved to be of importance.

Calibration curves of trace elements in the  $2 \cdot 10^{-3}$  to one mM concentration range, in the presence and absence of a large concentration of manganese, were plotted. It was established that the waves obtained were diffusion controlled both for individual and simultaneous determinations; the procedures were therefore suitable for quantitative determinations. The error of determination at 5–15 p.p.m. of trace metal to manganese was 10%.

The calculated diffusion current constants agreed satisfactorily with data reported in the literature. Excess manganese had no effect on  $i_d/C$ ,  $m$ ,  $t$  and  $D$ . Cobalt interfered with the determination of zinc.

### INTRODUCTION

The polarograph has been successfully applied for the determination of the purity of metals, such as high purity aluminium<sup>7,8</sup> and refined lead<sup>10</sup>. This paper describes its application for the simultaneous determination of traces of copper, cadmium, nickel and zinc in electrolytic manganese metal (99.8 — 99.95% pure), and in purified electrolytic manganese salt solutions.

The manganese salt solutions contained 10–120 g per litre manganese, as manganese sulphate. At the lower concentrations, 80–100 g per litre ammonium sulphate was also present.

From the experience gained in this laboratory, it was established that methods for the determination of trace elements should avoid the removal of manganese by precipitation, especially in the hydroxide form. The bulk of manganese hydroxide caused marked coprecipitation of trace elements. Attempts to prevent or minimize this effect were unsuccessful.

Some information has been published concerning the polarographic determination of metallic impurities in excess manganese. Perec<sup>5</sup> reported the direct polarographic determination of 0.5—2.0 p.p.m. of cobalt in pure manganese salt. The manganese salt served as the supporting electrolyte. Portnow and Suschencova<sup>6</sup> used a supporting electrolyte composed of ammonium chloride, ammonium carbonate and ammonium hydroxide for the simultaneous determination of copper, nickel and cobalt in active pyrolusite. Iron was reduced to the ferrous state and determined in a slightly ammoniacal tartrate supporting electrolyte.

Voriskova<sup>9</sup> investigated the use of 1 M ammonium chloride + 1 M ammonium hydroxide as a supporting electrolyte and suggested the simultaneous determination of copper, cadmium, cobalt and manganese in this medium. Heyrovsky<sup>1,2</sup> demonstrated that copper, cadmium, nickel, zinc and manganese could be determined simultaneously in a supporting electrolyte composed of 1 or 0.5 M of ammonium chloride and ammonium hydroxide, provided the various metals were present in approximately equal concentrations.

The above information was utilized in this laboratory for the simultaneous determination of traces of copper, cadmium, nickel and zinc in electrolytic manganese metal and salt solutions in a 1 M ammonium chloride + 1 M ammonium hydroxide supporting electrolyte. The base solution also contained 5% of ammonium sulphate to eliminate the interference of lead on the copper wave, 0.01% of gelatin as maxima suppressor and 2% of sodium sulphite to eliminate the effect of dissolved oxygen.

Methods for the determination of traces of lead and elemental sulphur in manganese metal and salt solutions developed and applied in this laboratory will be discussed in subsequent papers.

## EXPERIMENTAL

### *Materials*

AnalaR grade reagents and double-distilled water were used. Gelatin of ordinary grade was suitable.

The following standard solutions (400 mg per litre) were prepared: (1) cupric nitrate, (2) cadmium chloride, (3) nickel sulphate, (4) zinc chloride, (5) lead nitrate, (6) cobaltous and cobaltic nitrates. Other stock solutions of the following reagents were prepared: (1) 5 M ammonium chloride, (2) 0.5% gelatin in 0.05% hydrochloric acid (to prevent bacterial contamination<sup>4</sup>), (3) 20% sodium sulphite.

A purified triple-distilled mercury was used for the dropping mercury cathode (D.M.C.), and purified undistilled mercury for the mercury pool anode (M.P.A.).

### *Apparatus*

Data were obtained from a Tinsley pen recording polarograph type MK/14 with the internal M.P.A. cell supplied by the firm. The cell was thermostated to  $25 \pm 1^\circ\text{C}$ .

The temperature of the cell was measured and the results were corrected (2% per 1°C) and expressed at 25°C.

The slower 4 in. voltage drive of the polarograph was applied to improve wave separation, especially those of zinc and manganese. The polarogram was recorded between  $-0.1$  and  $-1.3$  v with full damping and a counter current of approximately half the maximum value.

Characteristic polarographic properties of the capillary at the open circuit were drop time,  $t = 2.6$  sec per drop, and weight of mercury,  $m = 3.49$  mg per sec at a mercury head of 71 cm.

A 0.5 ml micrometer syringe with  $2 \cdot 10^{-4}$  ml divisions was used for the measurement of small increments of standard solutions.

### *Preparation of solutions*

a) *Manganese metal*: A sample of 1.0—1.2 g of ground manganese was dissolved in 20 ml of dilute hydrochloric acid (1 : 1). Concentrated nitric acid (0.3 ml) was added and the solution evaporated to dryness. A solution of the residue in 5 ml of concentrated hydrochloric acid was evaporated to dryness; this operation was then repeated to obtain a pink coloured residue free from nitrogen oxide gases. This residue was dissolved in redistilled water containing a few drops of concentrated hydrochloric acid, transferred to a 50 ml volumetric flask and diluted to volume.

b) *Manganese salt solutions*: The manganese salt solution was diluted to a concentration of 20—24 g per litre. This was important to obtain the maximum sensitivity of the method and still avoid subsequent heavy precipitation of manganese hydroxide.

### *Determination*

5 ml of the manganese metal or salt solution were transferred to a 50 ml volumetric flask. The following reagents were added in the indicated order and diluted to volume: (1) 2.5 g ammonium sulphate (unless the solution already contained the reagent), (2) 10 ml ammonium chloride, (3) 1 ml gelatin, (4) 4 ml of 20% ammonium hydroxide, (5) 5 ml sodium sulphite. The polarogram of this solution was recorded. The diffusion current,  $i_d$  in microamperes, was calculated from the cuprous copper, cadmium, nickel and zinc waves. The half-wave potential (H.W.P.) of each trace element was also calculated.

### *Blanks*

a) *Manganese metal*: A blank was determined by evaporating a solution of 30 ml dilute hydrochloric acid (2 : 1) and 0.3 ml concentrated nitric acid following the same procedure as described above.

b) *Manganese salt solution*: Redistilled water was substituted for the manganese salt solution and the blank was determined as described above.



*Diffusion current vs concentration:*  $i_d$  was determined for manganese-free standard solutions of trace metals (concentrations,  $2 \cdot 10^{-3}$  to one mM), both individually and combined. This was repeated using standard additions of trace metals to very pure manganese metal and salt solutions. The average ratios  $i_d/C$  and  $i_d/\text{mg}$  per litre were calculated for each trace metal.

*Diffusion current constant:*  $m$  and  $t$  were determined at an applied constant potential equal to the H.W.P. of cuprous copper, cadmium, nickel and zinc using manganese-free base solutions and solutions containing 10–12 g per litre of manganese, and the expression  $i_d/C m^{2/3} t^{1/6}$  calculated for each case.

## RESULTS AND CONCLUSIONS

The divalent manganese-ammonia complex was reduced in the described medium at  $-1.46$  v, a H.W.P. more negative than that of the trace metals (Table I). Well defined waves (Figure 1) were developed, particularly for cuprous copper, cadmium and nickel. Since the zinc wave precedes that of manganese by only 0.28 v, its limiting current was slightly distorted, especially at the lower zinc to manganese concentration ratios. Nevertheless zinc estimation was still possible.

Reduction waves of manganese-free standard solutions and standard additions of trace metals to a very pure manganese, both for individual and simultaneous determination, were diffusion controlled, i.e., the average calculated ratios of  $i_d/C$  and  $i_d/\text{mg}$  per litre, listed in Table I, were constant within the accuracy of the method.

TABLE I

### *Polarographic characteristics of copper, cadmium, nickel and zinc*

Capillary characteristics were measured at applied voltage in a 1 M ammonium chloride + 1 M ammonium hydroxide supporting electrolyte. In all cases 0.01% gelatin, 2% sodium sulphite and 5% ammonium sulphate were present. Half-wave potential is in volts and referred to the mercury pool anode,  $i_d$  in microamperes,  $C$  in millimoles per litre,  $m$  in mg per sec and  $t$  in sec per drop at  $25 \pm 1^\circ\text{C}$ .

	Cuprous copper	Cadmium	Nickel	Zinc
H.W.P.	−0.33	−0.65	−0.98	−1.18
$t$	2.64	2.55	2.29	2.10
$m$	3.536	3.587	3.554	3.520
$i_d/\text{mg per litre}^*$	0.0810	0.0890	0.163	0.157
$i_d/C$	5.149	10.03	9.566	10.26
$i_d/C m^{2/3} t^{1/6}$	1.888	3.653	3.554	3.831

\* Values were corrected 2% per degree and expressed at  $25^\circ\text{C}$ .

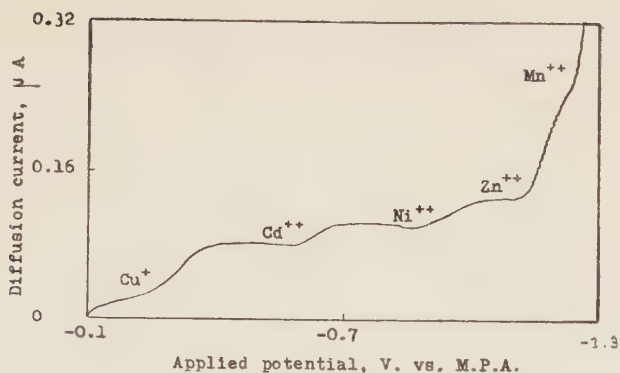


Figure 1

Simultaneous determination of copper, cadmium, nickel and zinc in excess manganese.\*  
 Containing 10 g/l manganese,  $6.3 \cdot 10^{-3}$  mM/l copper,  $3.1 \cdot 10^{-3}$  mM/l cadmium,  $5.6 \cdot 10^{-3}$  mM/l nickel and  $9.2 \cdot 10^{-3}$  mM/l zinc.

No influence was observed on  $m$  and  $t$ , and hence on  $i_d/C m^{2/3} t^{1/6}$  or the diffusion coefficient,  $D$ , because of the presence of 10–12 g per litre of manganese. The average values of  $i_d/C m^{2/3} t^{1/6}$  (Table I) agreed satisfactorily with similar data reported in literature<sup>3</sup> when the interpretation of the nickel and zinc waves, in the presence of manganese, was carried out as demonstrated in Figure 3 and corrected for the total blank. Figure 2 is a polarogram of the manganese metal blank that shows the presence of cuprous copper and zinc waves indicating the need for a blank correction.

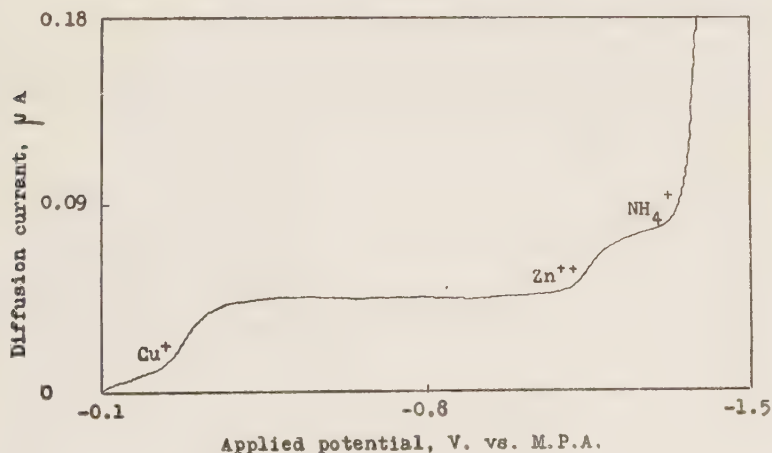


Figure 2

Polarogram of blank for manganese metal.\*

Containing the residue of 15 ml hydrochloric acid (2 : 1) and 0.15 ml concentrated nitric acid in 50 ml volume.

\* A supporting electrolyte composed of 1 M ammonium chloride + 1 M ammonium hydroxide containing 0.01% gelatin, 2% sodium sulphite and 5% ammonium sulphate was used unless mentioned otherwise.

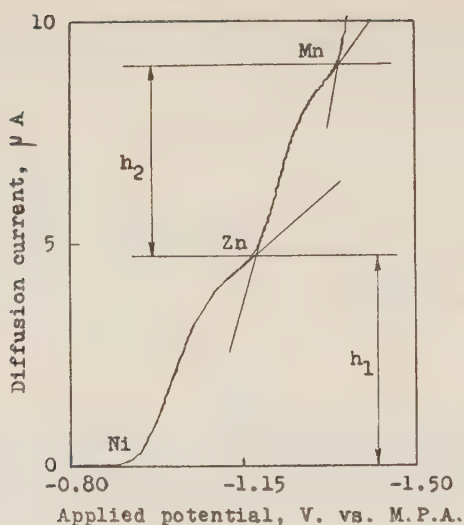


Figure 3

Interpretation of nickel and zinc reduction waves in excess manganese.\*  
Containing 10 g/l manganese, 0.52 mM/l nickel and 0.43 mM/l zinc.

This method is, therefore, suitable for the simultaneous determination of traces of copper, cadmium, nickel and zinc in electrolytic manganese metal and salt solutions. The minimum detectable concentration of each trace metal was 5–15 p.p.m. in manganese metal and 0.1–0.3 p.p.m. in the manganese salt solutions. The accuracy of determination was as follows:

Concentration in mM	% Error
$2 \cdot 10^{-3} - 10^{-2}$	$\pm 10$
$10^{-2} - 10^{-1}$	$\pm 5$
$10^{-1} - 1$	$\pm 2$

If lead was added in the absence of ammonium sulphate, the resultant lead wave overlapped that of cuprous copper. This interference, however, was completely eliminated by the addition of 5% ammonium sulphate (Figure 4). Additions of cobaltous and cobaltic ions increased the zinc wave height in proportion to the concentration of cobalt. The cobalt constant,  $0.152 \mu\text{A}/\text{mg}$  per litre, deviated only by 3.5% from that of zinc. Therefore the combined wave in this instance equalled the sum of zinc and cobalt concentrations. Cobaltic ion produced another wave between those of copper and cadmium, but this had no significant interference in practical application.

\* A supporting electrolyte composed of 1 M ammonium chloride + 1 M ammonium hydroxide containing 0.01% gelatin, 2% sodium sulphite and 5% ammonium sulphate was used unless mentioned otherwise.



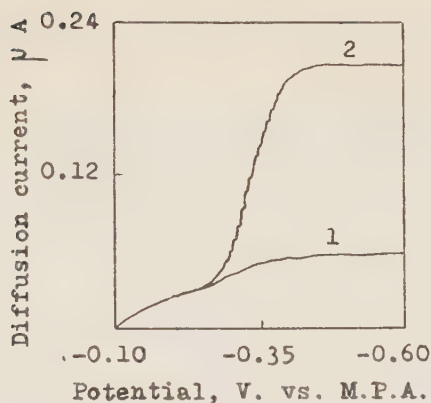


Figure 4

Elimination of lead interference on copper.\*

Containing 10 g/l manganese and 0.16 mM/l lead, (1) with 5% ammonium sulphate, (2) without ammonium sulphate.

#### ACKNOWLEDGMENT

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\* A supporting electrolyte composed of 1 M ammonium chloride + 1 M ammonium hydroxide containing 0.01 % gelatin, 2% sodium sulphite and 5% ammonium sulphate was used unless mentioned otherwise.

# AN ANALYTICAL METHOD FOR THE DETERMINATION OF HYDROBROMIC ACID IN BROMINE

D. KAPLAN AND I. SCHNERB  
*Research Council of Israel, Jerusalem*

## ABSTRACT

By shaking bromine, containing hydrobromic acid, with a 0.25 N potassium bromide solution, the whole amount of hydrobromic acid can be extracted from it. The bromine absorbed simultaneously by the potassium bromide solution is removed by air, and the remaining hydrobromic acid is titrated with a 0.02 or 0.01 N NaOH solution. Hydrobromic acid formed during the test by hydrolysis is determined separately.

Tests carried out with pure bromine, to which known amounts of hydrobromic acid had been added, showed results with a maximum deviation of  $\pm 0.9\%$ .

Hydrobromic acid in small amounts may occur in bromine. It may originate from the oxidative action of bromine on extraneous organic impurities, or from water contained in the bromine. Water, which according to the literature<sup>1</sup> dissolves bromine to an extent of 0.05%, forms hydrobromic acid by hydrolysis. Moreover, the acid formed increases the solubility of water in bromine.

No method for the determination of hydrobromic acid in bromine is known. Such a method appears to be of importance, e.g. for the study of the corrosive properties of bromine. Thus, it has been found that bromine corrodes lead only when small amounts of hydrobromic acid are present<sup>2</sup>.

An analytical method for the determination of hydrobromic acid in bromine has, therefore, been developed.

## PRINCIPLE OF THE METHOD

Preliminary experiments showed that hydrobromic acid can be absorbed quantitatively in potassium bromide solutions. By shaking bromine, which contains hydrobromic acid, with the solution of the bromide, the whole amount of hydrobromic acid contained in the bromine can be extracted from it; at the same time a certain amount of bromine is absorbed forming a polybromide ion. When the bromine is removed from the bromide solution by a stream of air or an inert gas, the hydrobromic acid remains and can be titrated acidimetrically.

## HYDROLYSIS OF BROMINE BY AQUEOUS SOLUTIONS OF POTASSIUM BROMIDE

Potassium bromide solution hydrolyses bromine to a certain extent, dependent on the concentration of this solution. The concentration was, therefore, determined at which a minimum of hydrolysis takes place.

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For this purpose bromine, free from hydrobromic acid, was prepared by shaking bromine with lead dioxide for 3—5 minutes in a closed cylinder and filtering the bromine through glass wool.

In a gas-washing bottle, 10 cm<sup>3</sup> of this bromine was added to 50 cm<sup>3</sup> of potassium bromide solutions of 2 to 0.125 normality. The bottle was protected from light by a black cloth and connected to a series of washing bottles containing sodium hydroxide solution. By a stream of air, the bromine was driven out at room temperature and finally at 35—40°C, and absorbed in the sodium hydroxide solutions. The resulting potassium bromide solution was then transferred to an Erlenmeyer flask, and the hydrobromic acid, formed by hydrolysis, was titrated (Methyl Orange). The results are summarized in Table I.

TABLE I

Potassium bromide concentration (N)	Time required to remove bromine by air at room temperature (min)	cm <sup>3</sup> 0.01 N NaOH for 50 cm <sup>3</sup> of potassium bromide solution
2	65	1.6
1	50	1.0
0.5	30	0.6
0.25	25	0.4
0.125	35	0.5
distilled water	70	2.1

The current of air had a constant velocity of 100 l/hr in all experiments.

The shorter the time required for the removal of the bromine from the potassium bromide solution, the smaller the degree of hydrolysis. For the method to be employed a concentration of 0.25 N potassium bromide was chosen.

It should be borne in mind that the amount of bromine absorbed by KBr solution increases with the concentration of the salt. Therefore also the time required for the removal of the dissolved bromine by a current of air (or inert gas) increases with that concentration. It is, therefore, understandable that hydrolysis occurs in more concentrated solutions of bromine to a larger extent than in dilute ones, the time of contact being longer.

#### PROCEDURE

A quantity of 10 to 50 cm<sup>3</sup> of bromine is added to 50 cm<sup>3</sup> of a 0.25 N potassium bromide solution in a 100 cm<sup>3</sup> cylinder, closed with a ground joint stopper and covered with a black cloth. After shaking the cylinder for one minute and waiting for another five minutes, the aqueous solution is separated in a separating funnel from the part of the bromine which did not dissolve, and is transferred to a gas washing bottle. The bromine is removed and the acid titrated as described before. The bromine layer, which is free from hydrobromic acid, is used for a blank test.



TABLE II

Quantity of bromine tested (cm <sup>3</sup> )	Time required to remove the bromine (min)	0.01 N NaOH used (cm <sup>3</sup> )	0.01 N NaOH for blank (Hydrolysis) (cm <sup>3</sup> )	0.01 N NaOH after reduction of blank (cm <sup>3</sup> )	HBr in 1000 cm <sup>3</sup> of bromine (mg)
50	20	5.20	0.6	4.60	74.4
40	20	4.28	0.6	3.68	74.5
30	20	3.28	0.52	2.76	74.3
20	15	2.28	0.45	1.83	74.0
10	10	1.25	0.33	0.92	74.0

The table shows that the result is independent of the amount of bromine employed.

In order to assess the reliability of the method, measured amounts of hydrobromic acid were added to samples of bromine, freed from hydrobromic acid and the solutions analysed as above. The results of Table III show a maximum deviation of  $\pm 0.9\%$ .

TABLE III

Quantity of bromine tested (cm <sup>3</sup> )	Hydrobromic acid added (mg)	Hydrobromic acid found (mg)	Deviation (%)
20	3.24	3.22	-0.6
10	3.24	3.21	-0.9
10	2.43	2.45	+0.8
10	3.24	3.22	-0.6
10	3.24	3.27	+0.9

## ACKNOWLEDGMENT

The authors wish to thank Dr. M. R. Bloch, Director of Research and Development of Mifalei Yam Hamelah, for helpful discussions and suggestions.

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# PREPARATION OF PULPS BY THE SULPHATE PROCESS FROM *EUCALYPTUS ROSTRATA* GROWN IN ISRAEL, AND THEIR BLEACHING

M. LEWIN AND A. LENGYEL

*Ministry of Agriculture, Institute for Fibres and Forest Products Research, Jerusalem*

## ABSTRACT

Following an investigation on the chemical composition and fibre dimensions of *E. rostrata* grown in Israel, in which the properties of this species were found to be similar to Australian *E. regnans* rather than to Australian *E. rostrata*, a study of the cooking conditions of this wood, the properties of the sulphate pulps and the bleaching of these pulps was carried out in these laboratories and is reported in the present paper.

The requirements of alkali at a sulphidity of 25%, the temperature and time schedule of the digestions were determined for wood samples from Hadera and from the Negev and compared to the other hardwoods and Australian eucalypts.

The influence of the initial alkali on the total yield, screenings, alkali consumption, permanganate number, viscosity and the properties of pulps obtained was investigated.

The beating and strength characteristics of the Hadera and Negev pulps were studied and compared to those of standard Maryvale "mixed species" pulp. The pulps are characterized by a relatively high tearing strength and bulk.

The bleaching of the pulps was investigated by the 3 stage (CEH) and the 4 stage (CHEH) procedures at varying amounts of available chlorine in the different stages. Bleaching trials are also reported with the hypochlorite-bromide system, adding bromide to the last hypochlorite stage — which caused an acceleration of the bleach, a decrease in the consumption of alkali and yielded pulps with higher viscosities and brightnesses.

The strength characteristics of the bleached pulps were studied and compared to those of unbleached pulps.

## INTRODUCTION

In Australia, a number of *Eucalyptus* species such as *Eucalyptus regnans*, *E. gigantea*, *E. obliqua*, *E. sieberiana*, *E. viminalis* are utilized for the production of pulp and paper<sup>1</sup>. *E. rostrata* is used there in construction work and for sleepers, paving blocks and fence posts, but it has not been considered suitable for cellulose and pulp and paper production, chiefly because of its high cellular kino content which might cause a high chemicals demand in the digestion stage and give rise to difficulties in the bleaching process<sup>2</sup>.

In other countries, however, this species has been tried for the production of dissolving pulp<sup>3,4</sup>, but no data seem to have been published on its pulping and utilization for paper production.

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The first indications as to the possible suitability of the *E. rostrata* grown in Israel for the production of pulp and paper were obtained in this laboratory<sup>5</sup> in 1951, when a preliminary investigation of the chemical composition of the Israeli species showed it to be significantly different from the same species grown in Australia<sup>6</sup>. The C.B. cellulose content was found to be 49–50% and the solubles in 0.5% sodium hydroxide were 18–21% as compared to 39.6% C.B. cellulose and 34% solubles in 0.5% sodium hydroxide in the Australian samples, and to 37.8% C.B. cellulose found in Italian *E. rostrata* by Brunetti<sup>4</sup>. Since the chemical composition of the Israeli *E. rostrata* was found to be similar to the composition of the Australian *E. regnans*<sup>7,8</sup>, it was decided to investigate the possibilities of pulping Israeli *E. rostrata* and bleaching the pulp obtained. Optimal pulping conditions were sought and investigations were made on the properties of the pulps and strength relationships of the resultant papers, on the bleaching of the sulphate pulps, and on the character of fine papers which could be made from the bleached pulps.

The sulphate process was chosen for this investigation because of its high flexibility regarding the wide range of paper grades which can be prepared from sulphate pulps, as well as because of the possibility of adapting this process to other raw materials such as pines and agricultural residues.

#### EXPERIMENTAL PROCEDURE

##### *Raw materials*

One sample of *E. rostrata* investigated was brought from the 10–15 year old Hadera forest which grows on heavy soil and enjoys a relatively high amount of rainfall (600–700 mm). A second sample was taken from the 11 year old Negev forest growing in desert conditions on sandy dune soil with an extremely low amount of rainfall (100 mm). Each sample was prepared from three trees. Three disks were taken from each tree at three different positions in the tree.

In the first series of cooks, the barked wood sample used was composed of air-dried factory-made chips (Sefen factory) from the Hadera forest, containing 10% moisture. Before the investigations the chips were stored in a closed room, away from any extreme atmospheric conditions and direct sunlight.

A second series of cooks carried out using chips prepared by hand from fresh green wood gave similar results to those obtained from machine-made chips. The Negev sample was cooked in the form of handmade chips from the barked wood.

The basic density of the wood samples, determined by the Tappi standard method and expressed as oven dry weight on the soaked volume, was 34 lbs/ft<sup>3</sup> (0.54 g/cm<sup>3</sup>) for the Hadera sample and 31 lbs/ft<sup>3</sup> (0.50 g/cm<sup>3</sup>) for the Negev sample.

Green samples, when brought from the Hadera stand to the laboratory immediately after logging, contained 57% oven dry matter.



*Equipment and experimental layout*

Two experimental layouts were employed according to the amounts of material used for a single cook.

In one layout an amount of chips corresponding to 250 g oven dry weight was used. The cooks were performed in a rotary battery of six autoclaves especially designed in this laboratory\* of 1 litre capacity each, revolving about a common axis, in a common electrically heated and thermostatically controlled air bath. The time at maximum temperature of the six cooks can be varied by stopping the rotation for a short time (2—3 min), removing one or more small autoclaves and substituting a dead weight for them. Afterwards the rotation and heating is continued. The removed autoclaves were immediately cooled in cold water, opened, the contents dumped, the black liquor analysed for alkali, the chips disintegrated and further processed as described below.

In the second layout, two rotary digesters of 14 and 12 litre capacity were used. The autoclaves were charged with 1 kg of oven dry wood per cook, except in cook No. 11 and cook No. 5b, the pulp from these cooks being intended for bleaching trials. A liquor ratio of 3.4 litre per kg of wood and a sulphidity of 25% were maintained in the whole series of trials conducted. During the cooks, small samples of cooking liquor from the digester were taken at time intervals as indicated in Table II, and the total alkali and sulphide determined according to Tappi standard methods. After terminating the cook, the pressure was relieved, and the contents of the digester dumped. Only in the cooks with a very high alkali charge (20 and 22% on oven dry wood) did a small part of the wood chips disintegrate in the digestion and the rest retained their original form. In all the other cooks there was almost no disintegration, but the chips became softened to such a degree that they fell apart under soft pressure of the fingers or on energetic shaking of a test tube with water. The cooked chips were disintegrated in a turbine type pulp breaker, or, in one instance, in the Tappi standard disintegrator. It is realized that the experimental setup used does not give definite information on the disintegration of the chips cooked at the various conditions used in the trials. This question, as well as the possibility of effecting disintegration by blowing the digester, will have to be answered by industrial trials.

The disintegrated pulp was filtered through cloth on a Buchner funnel, thus collecting all solid matter not dissolved by the cooking liquor. The percentages of this collected matter, including fine fibres, are given in the tables as the yield figures. In industrial practice there will most probably be a washing loss depending on the procedure and machinery used in collecting and washing the pulp.

The filtered pulp generally having a consistency of 16—18% was weighed, thoroughly mixed and two independent average samples were taken for determination

\* Built by E. Sokhachever & Co., Jerusalem.

of moisture. The mean of the two determinations which always agreed within 0.5% was used to calculate the dry weight and the unscreened total yield. Subsequently the pulp was screened in the Lorentzen and Wettress strainer through a slotted plate with 0.2 mm openings, and the part of the pulp that did not pass the screen after prolonged washing with running water was collected, dried and calculated as screenings, as a percentage of the original oven dry wood.

Chemically, the pulps were characterized by determining the permanganate number and the percentage of residual lignin by the Tappi standard methods. In the spent cooking liquor, the active alkali was determined and corrected for sulphide. In several cases the cuprammonium viscosities of 0.5% solution of the pulp samples were measured by the British Shirley (1932) standard procedure and converted to Tappi viscosities in centipoises (cp) of a 1% solution by means of Tappi Data Sheet 1130.

For further characterization, the pulps were beaten in the case of 1 kg cooks in the Valley Niagara beater at 1.5% consistency, and in the case of the 250 g cooks in the Lampen Mill, at a consistency of 3%. In the case of the Valley beater, samples were taken at 15 min intervals. In the case of the Lampen mill, three separate samples of 30 g each were beaten for 10,000, 20,000 and 30,000 revolutions. The freeness was determined in the Williams Precision Freeness Tester and the results were converted to Canadian standard freeness figures by means of Table 20a of the Tappi Data Sheets. Handsheets were then prepared in the Valley sheetmaking apparatus, pressed once between blotters at 5 kg/cm<sup>2</sup> and dried between blotters in the Williams Sheet Drying Oven. The dry handsheets were conditioned in a constant temperature and relative humidity room at 20°C and 65% R.H. for 24 hours before determining the strength properties. The following strength properties were determined by the Tappi standard methods and definitions: tear factor, burst factor, breaking length and folding endurance. The air permeability was also determined in the Gurley permeometer and the specific volume (bulk) calculated from the basic weight and thickness of the single sheets as determined by the thickness gauge, both according to the Tappi standard procedure.

Since some confusion exists in the technical literature concerning definitions of properties of papers and pulp and the numerical units used in their evaluation, the definitions and units used throughout this report are given in Appendix I.

## COOKING VARIABLES AND PROPERTIES OF PULPS

### *Preliminary experiments*

Several series of cooks were carried out on the Hadera sample to test the effect of temperature, time of cook and amount of alkali on the total yield, screenings, permanganate number and alkali consumption. The liquor to wood ratio in these experiments was kept at 3.

Series EH2, EH3 and EH4 were carried out at temperatures of 150°C, 155°C and 160°C, respectively, in the small rotating autoclaves. For each cook an amount of wood corresponding to 250 g oven dry matter, consisting of chips prepared by hand from fresh wood, was used. The results of these series of experiments are summarized in Table I.

TABLE I  
*Cooking data of E. rostrata from Hadera (Series 2)*

(Sulphidity 25%, wood to liquor ratio 1 to 3, dry wood substance taken for each cook 250 g, chips handmade)

Cook No.	Alkali (% Na <sub>2</sub> O)	Temp. (°C)	Cooking time (min)	Yield total (%)	Screenings (%)	Perman- ganate number	Residual alkali (gNa <sub>2</sub> O/l)	Na <sub>2</sub> O consumed (% on wood)
EH 2/0	13	150	90+120	52	32	35	2.2	12.5
EH 2/1	13	150	90+180	50	20	27	2.2	12.5
EH 2/2	14	150	90+120	48	16	27	4.1	13.0
EH 2/3	14	150	90+180	47	8	26	3.7	13.1
EH 2/4	15	150	90+120	48	2	21	5.6	13.6
EH 2/5	15	150	90+180	47.5	2	22	4.7	13.9
EH 3/0	14	155	90+120	50	5	23	3.4	13.2
EH 3/1	15	155	90+120	47.5	1	21	4.1	14.0
EH 3/2	14	155	90+150	48	3	22		
EH 3/3	14	155	90+180	47	3	23	3.2	13.2
EH 3/4	15	155	90+150	48	2	21	4.7	13.9
EH 3/5	15	155	90+180	49	0.8	20	4.8	13.8
EH 4/0	14	160	90+120	48	3	23	3.6	13.1
EH 4/1	15	160	90+120	50	1.6	20	4.7	13.9
EH 4/2	14	160	90+150	50	3.2	24	2.1	13.5
EH 4/3	14	160	90+180	51	2	22	1.8	13.6
EH 4/4	15	160	90+150	51	1.8	20	2.5	14.4
EH 4/5	15	160	90+180	47	1.2	19.5	3.4	14.2

It can be seen from this table that at lower concentrations of alkali the absolute amounts of alkali consumed are lower than at the higher initial alkali concentrations. The degree of exhaustion of the initial alkali is higher for the lower initial concentrations of alkali and increases slightly with the time of cook. In general it can be seen that the degree of exhaustion increases with the temperature, and that while at 13% initial Na<sub>2</sub>O only about 4% remained in the black liquor at 150°C, at 15% initial Na<sub>2</sub>O 7.2% remained at 150°C after 3 hours at temperature, and 5% remained at 160°C.

It appears from Table I that the minimal alkali demand is between 14 and 15% Na<sub>2</sub>O on wood, 13% giving an excessive amount of screenings and also a very high permanganate number of the screened pulp. As for the influence of cooking temperature and time, it seems that at all temperatures studied, at least at the lower limit of the initial alkali (14%), the required cooking time is 3 hours at temperature for the cooks which take 1½ hours to reach cooking temperature. At 160°C and



15% alkali 2 hours cooking appear to be sufficient. The yield figures vary somewhat between 48 and 51%, but this seems to be caused by unavoidable varied mechanical losses incurred in handling small amounts.

The permanganate number for the same initial alkali seems to be the lowest at 160°C, and to decrease with increasing time of cooking.

### *The cooking variables*

Another series of cooks (EH1) was carried out in order to determine more accurately the influence of the initial alkali amount on the yield and also for the study of the physical properties of the pulps obtained. In these cooks a quantity of chips corresponding to 1 kg of oven dry material was used in each cook, at a liquor ratio of 3.4. The chips were machine made from *E. rostrata* logs taken from the Hadera stand and stored in the laboratory several months before cooking. The moisture content of the chips was 10%.

The results of this series of cooks are summarized in Table II and Figures 1 and 2.

TABLE II

#### *Cooking data of E. rostrata from Hadera (Series 1)*

(Chips machine prepared, oven dry weight of chips in each cook 1 kg, cooking liquor 3.4 l (for 1 kg chips), sulphidity 25%)

Cook No.	Alkali (%Na <sub>2</sub> O)	Temp. (°C)	Cooking time (min)	Yield total (%)	Screening (%)	Per- man- ganate number	Residual lignin in pulp (%)	Residual alkali consumed on wood (g Na <sub>2</sub> O/l)	Na <sub>2</sub> O consumed on wood (%)	0.5% Cupr fluidity (rhes)	TAPPI viscosity (1% Cu am. cp)
EH 1/3	22	160	90+90	42	0.4	14	2.5	16.1	16.5	12.5	33
EH 1/4	20	160	90+90	46	<0.5	16.2	2.7	12.0	15.9	10.7	42
EH 1/5	18	160	90+90	47	<0.5	16.2	2.6	10.0	14.6	9.5	50
EH 1/6/8	16	160	90+90	48.5	0.7	19.2	3.7	7.0	13.6	7.3	76
EH 1/9	15	160	90+90	53.5	2.9	26.0	6.1	6.3	12.8	7.6	71
EH 1/7	14	160	90+135	51	3.9	23.5	4.9	5.1	12.2	7.35	76
EH 1/10	16	150	90+180	52	0.7	21.5	4.9	6.2	12.8	8.1	66

It is seen that with the decrease in initial alkali from 22% to 15% the total yield increases from 42% to 53.5%, the percentage of screenings, the permanganate number and the residual lignin increase, the alkali consumed decreases, while the viscosity (cp) increases strongly. Yields of unbleached pulps higher than 50% with a low percentage of screenings can be obtained with 15% with initial alkali, at 160°C and 90 min of cooking. It seems that it is not feasible at the conditions of cooking described in Table II to obtain pulps with permanganate number lower than 19.2. The yield decreases very considerably with the decrease in the permanganate number, so that at 16% alkali 47% of pulp with a permanganate number of 16 and at 22%

alkali only 42% of pulp with a permanganate number of 14 are obtained. It seems, therefore, that even for subsequent bleaching it is more advisable to prepare pulp with a permanganate number higher than 19, since the viscosities are also much higher. The viscosities of the pulps from cooks EH 1/6—8 (16%), EH 1/9 (15%) and EH 1/7 and EH 1/10 are very high compared with commercial sulphate pulps.

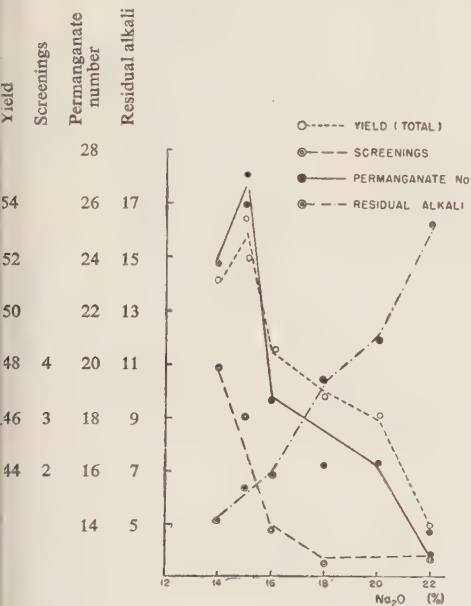


Figure 1  
Cooking results of *E. rostrata* (Hadera) at various alkali amounts.

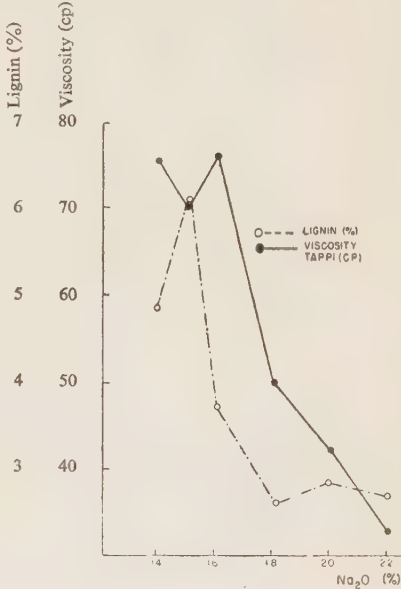


Figure 2  
Change in viscosity and lignin with amount of alkali in *E. rostrata* (Hadera).

The results in Table II differ somewhat from the results in Table I. The consumption of alkali is lower, the yield figures and permanganate numbers higher. These differences may be accounted for by the difference in cooking conditions. Possibly in the different intensity of mixing and size of the digesters.

It is seen that for yield and viscosity values a decrease in the temperature from 160°C to 150°C may be compensated by an increase in alkali from 15 to 16%.

Consumption of alkali

In Table III and Figure 3 the dependence of residual alkali on cooking time is represented. The figures were obtained by analysing aliquot samples of cooking liquor withdrawn at predetermined time intervals. It is seen that a major part of the alkali was consumed before the reaction mixture reached the maximum temperature.

TABLE III  
Dependence of residual alkali on cooking time  
(Concentrations of total alkali (NaOH + Na<sub>2</sub>S) computed as Na<sub>2</sub>O in g/l)

Cooking time (min)	Number of cook							
	EH 1/3	EH 1/4	EH 1/5	EH 1/6	EH 1/7	EH 1/8	EH 1/9	EH 1/10
0	64	59	53	47	41	47	44	47
90	27.2	20.3	21	11.5	9.8	15	15.7	14.3
90+45	18.5	13.4	12.5	9.2	6.3	9.6	9.0	—
90+60	—	—	—	—	—	—	—	—
90+90	16.1	12.0	10.4	7.7	6.0	6.3	6.3	—
90+120	—	—	—	—	—	—	—	7.7
90+135	—	—	10	7.7	5.1	—	—	—
90+180	—	—	—	—	—	—	—	6.2

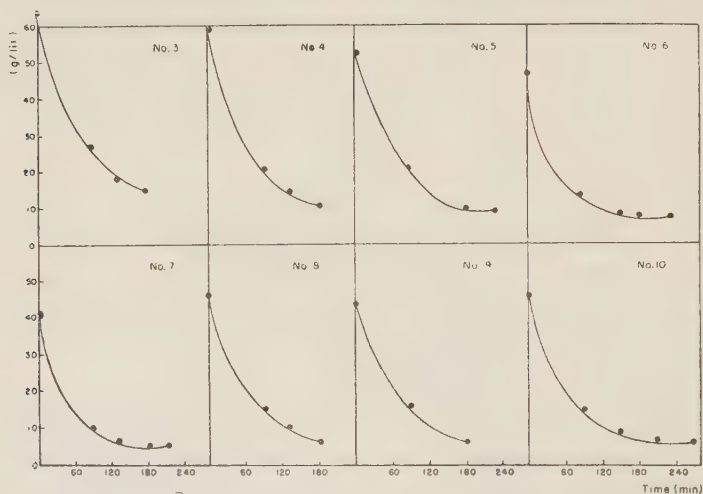


Figure 3  
Decrease in residual alkali with time of cooking in *E. rostrata*  
(Hadera). Series 1, cooks 3—10.

At the higher initial concentrations of alkali the residual alkali is high and, while for 20% of Na<sub>2</sub>O about 1/5 of the initial concentration remains in the black liquor, only about 1/7 remains in the case of 15% of initial alkali. Comparison of EH 1/8 and EH 1/10 shows the influence of increase in temperature on the rate of alkali consumption. A decrease of 10°C (from 160 to 150°C) necessitates an increase in time from 90 min to 180 min at the cooking temperature for the same extent of reaction.

#### Beating and strength characteristics

In Table IV and Figures 4—9 the beating characteristics, i.e. dependence of freeness, tensile strength, burst factor, tear factor and folding endurance of the pulps described (Table II), on the beating time, are represented.

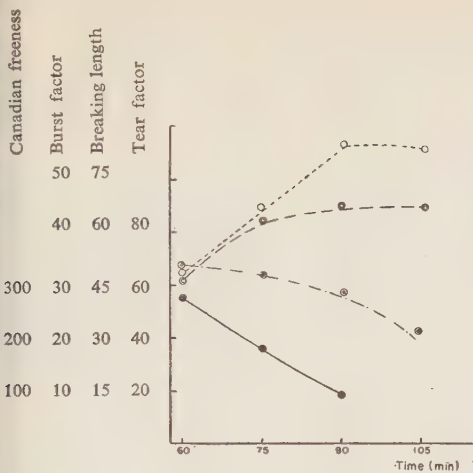


Figure 4  
Beating and strength characteristics of *E. rostrata* (Hadera) pulp cooked with 22%  $\text{Na}_2\text{O}$  (EH 1/3).  
Legend as in Figure 6.

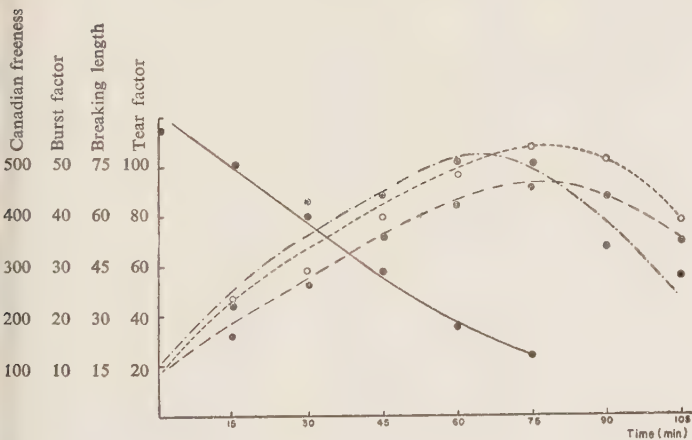


Figure 5  
Beating and strength characteristics of *E. rostrata* (Hadera) pulp cooked with 18%  $\text{Na}_2\text{O}$  (EH 1/5).  
Legend as in Figure 6.

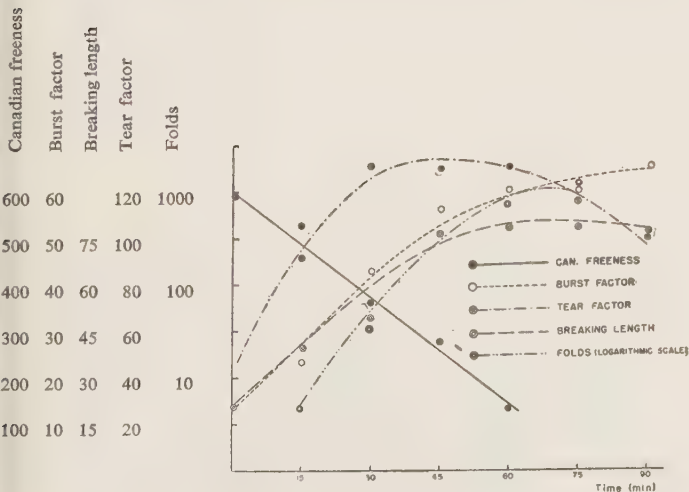


Figure 6  
Beating and strength characteristics of *E. rostrata* (Hadera) pulp cooked with 16%  $\text{Na}_2\text{O}$  (EH 1/6). The values of breaking length are given in meters  $\times 10^{-2}$ .



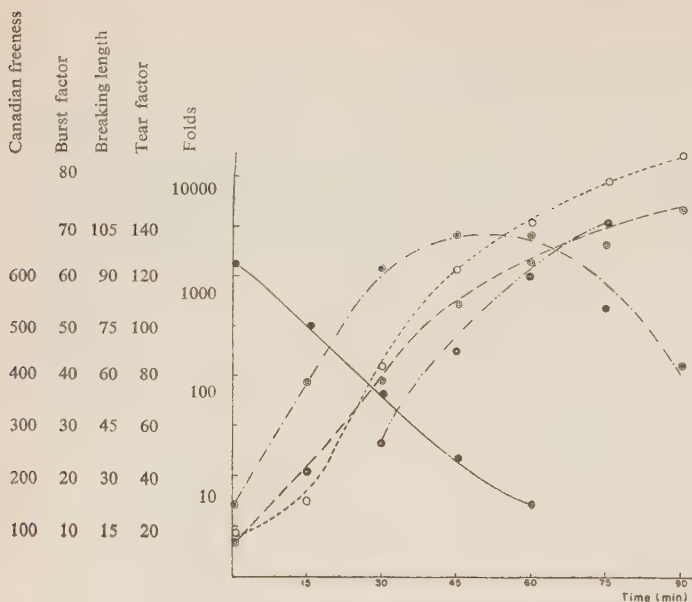


Figure 7

Beating and strength characteristics of *E. rostrata* (Hadera) pulp cooked with 15% Na<sub>2</sub>O (EH 1/9). Legend as in Figure 6.

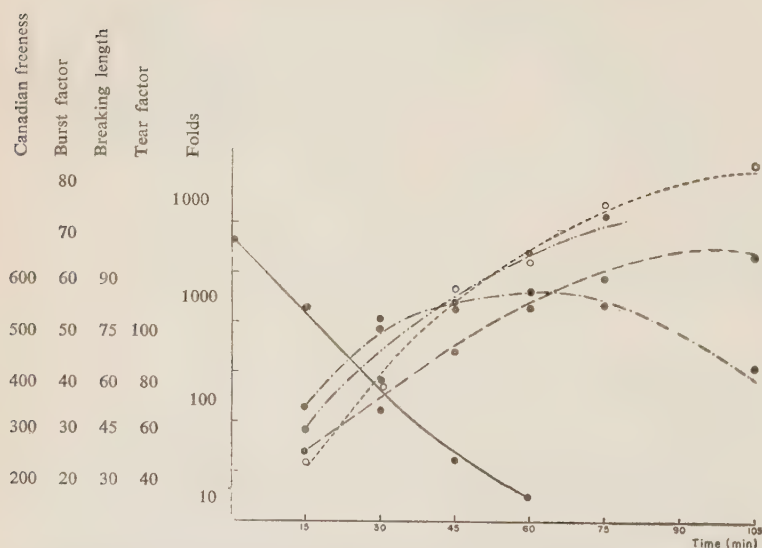


Figure 8

Beating and strength characteristics of *E. rostrata* (Hadera) pulp cooked with 14% Na<sub>2</sub>O (EH 1/7). Legend as in Figure 6.

The freeness values obtained after definite times of beating in the Valley beater are similar to those obtained for a commercial Finnish sulphate pulp beaten at the same conditions. The tearing strength increases up to values of 130–140 g at freeness values in the range of 250–150. The maximum tear factor is retained at up to 150 ml Canadian freeness and only on further beating a decrease is recorded. The burst factor increases steadily with beating and values higher than 80 kg were obtained. For freeness values of 150 ml, burst factors of up to 70 g per cm<sup>2</sup> per basic weight of paper sheet were recorded.

TABLE IV

*Beating characteristics of E. rostrata (Hadera) pulps (Series 1) (Valley Niagara beater)*

Cook No.	Time (min)	Canadian freeness (ml)	Tear factor (g)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)
<b>EH 1/3</b>						
22% Na <sub>2</sub> O, 160°C	60	275	68	32	4700	
	75	180	62	44	6300	
	90	90	56	56	6600	
	105		50	56	6600	
<b>EH 1/5</b>						
18% Na <sub>2</sub> O, 160°C	0	575	28.6	8.5	1350	
	15	500	45.6	23.4	2480	
	30	400	85.7	25.8	4000	
	45	285	95.5	40.0	5500	
	60	185	126	48.5	6000	
	75	125	108	54.0	7050	
	90		67.5	51.5	6750	
	105		57.2	40	5350	
<b>EH 1/6</b>						
16% Na <sub>2</sub> O, 160°C	0	587		13.3	2100	
	15	525	91.5	23.4	4100	5
	30	360	133	43.4	5000	35
	45	275	133	56.8	7800	
	60	143	130	60.0	7900	896
	75		117	60.0	8000	1049
	90		100	66.7	7900	
<b>EH 1/7</b>						
14% Na <sub>2</sub> O, 160°C	0	650				
	15	625	65	22	3700	30
	30	380	100	36	4900	295
	45	225	105	57	6700	400
	60	150	113	62	8100	1400
	75		99	73	8800	3500
	90		80	75	9800	7000
	105		82	83	9700	
<b>EH 1/9</b>						
15% Na <sub>2</sub> O, 160°C	0	625	28	9	1070	
	15	500	77	15	3200	
	30	360	124	44	5900	20
	45	235	139	61	8200	390
	60	140	136	72	9300	
	75		107	78	9900	3080
	90		83	83	11100	5000
<b>EH 1/10</b>						
16% Na <sub>2</sub> O, 150°C	0	605	17	8.5	2000	
	15	500	75	22	3500	
	30	430	86	35	5400	128
	45	250	95	58	7900	
	60	154	98	70	9100	1200
	75		93	83	9800	1640
	90		67	84	10400	4810

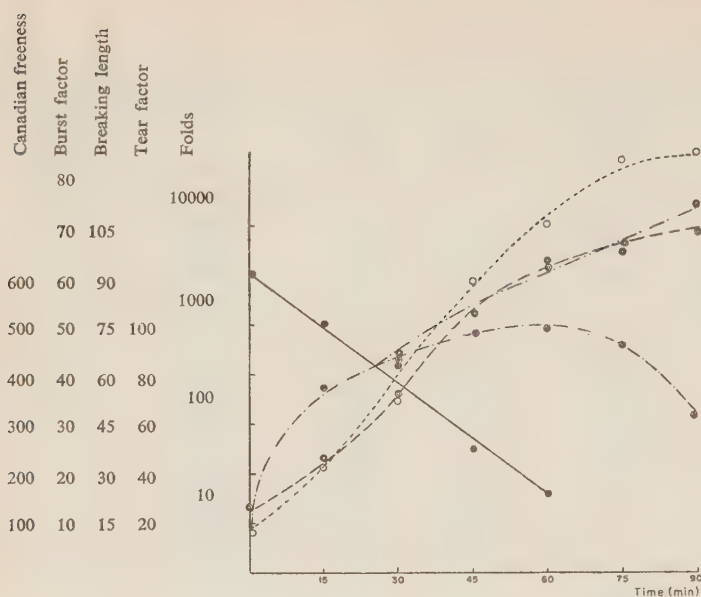


Figure 9  
Beating and strength characteristics of *E. rostrata* (Hadera) pulp cooked with 16% Na<sub>2</sub>O at 150°C (EH 1/10). Legend as in Figure 6.

Breaking length values of up to 11,000 m were reached on prolonged beating and in all cases the values increased with decrease in freeness. For freeness values of 150 ml, however, maximum breaking length values of only 9000 m were obtained. The folding endurance also increased with the beating time and at 150 ml freeness values of 1000—1400 double folds at a tension of 1 kg in the M.I.T. tester were obtained.

### Reproducibility of results

In order to check the reproducibility of the results, cook No. EH 1/9 was repeated and the results tabulated in Table V.

The comparison of the data in Table V and Tables II and IV shows that the data obtained are fairly reproducible. The difference in screened yield is not higher than 0.6% and the permanganate numbers differ by only one unit. Even these differences, as well as the differences in the strength data between the two experiments and especially in the relation between time and freeness values, may be attributed to the differences in the composition of the chips used, which were not screened.

The cooks EH 1/9a and EH 1/9b were carried out in the larger 12 litre capacity rotating digester with a quantity of chips corresponding to 1 kg of oven dry material and 3.4 litres of solution. The digester was therefore only partly filled and hence the mixing was particularly efficient. Another cook, EH 1/9c, was carried out in the same digester with a quantity of chips corresponding to 2.2 kg of oven dry material and 7.5 litres of solution, so that the digester was almost full. Other conditions remained exactly the same. In Table Va the results of this experiment are presented. The yield, permanganate numbers, viscosity of the pulp and strength characteristics

are seen to be very near to those of Table V. This would indicate that the cooking variables used in these cooks are fairly reproducible and not too dependent on the efficiency of mixing.

TABLE V

*Properties of E. rostrata (Hadera) sulphate pulp after various beating times (EH 1/9b)*

(Alkali 15%, sulphidity 25%, temp. 160°C, time 90+90 min, yield total 52%, screenings 2%, permanganate number 27)

Beating time (min)	Canadian freeness (ml)	Air permeability (sec/100cm <sup>3</sup> )	Tear factor (g)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)
0	625		33	10	2000	0
15	500		100	29	5100	10
30	350	6	121	48	7100	120
45	150	75	115	68	8600	817
60		560	100	73	10200	2500
75			86	79	10300	2400

The air permeability of the unbeaten pulp and after 15 min of beating is too great to be measured in the standard apparatus, and after 75 min it is very small.

TABLE Va

*Properties of E. rostrata (Hadera) sulphate pulp after various beating times. Beating characteristics in Valley Niagara (EH 1/9c)*

(Wood chips corresponding to 2.200 oven dry wood, Na<sub>2</sub>O on wood 15%, sulphidity 25%, temperature 160°C, time 90+90 min, yield total 50.5%, permanganate number 28, pulp viscosity: Shirley rhes 7.9, TAPPI cp 68).

Beating time (min)	Canadian freeness ml	Air permeability (sec/100 cm <sup>3</sup> )	Tear factor (g)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)
0	650	—	27	6.7	1350	0
15	500	—	81	26	4300	7
30	362	6	125	50	7000	105
45	175	44	120	67	8500	700
50	150	112	116	68	8800	1000
60	100	250	102	70	9000	1800

### *Dependence of strength properties on the initial alkali*

In Table VI and Figure 10 the influence of initial alkali concentration on the strength properties at a freeness of 150 ml is summarized. It is seen that all strength characteristics increase strongly with decrease of initial alkali, the optimum alkali amount being 15%. The decrease in temperature from 160° to 150°C, while bringing about a marked decrease in the tear factor, causes a considerable increase in folding endurance, bursting strength and breaking length. It is interesting to note from Table III that the time of beating required for a given freeness value decreases with



decrease in the initial alkali amount. For the pulp prepared with 22%  $\text{Na}_2\text{O}$  after 75 min of beating a freeness value of 180 ml is obtained, whereas for the pulp prepared with 16%  $\text{Na}_2\text{O}$  a freeness value of 143 is obtained already after 60 min. This difference is due to the hemicellulose content of the pulps<sup>9</sup>, the overcooked pulp having a much lower hemicellulose content.

TABLE VI

Comparison of the strength characteristics of *E. rostrata* (Hadera Series 1) pulps prepared with different  $\text{Na}_2\text{O}$  at 150 ml Canadian freeness

Cook No.	Alkali (% $\text{Na}_2\text{O}$ )	Tear factor (g)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)	Temp. (°C)
EH 1/3	22	60	47	6400		160
EH 1/5	18	104	52	6800		160
EH 1/6	16	130	56	7900	896	160
EH 1/9	15	136	71	9200	1000	160
EH 1/7	14	113	62	8100	1400	160
EH 1/10	16	98	71	9100	1200	150

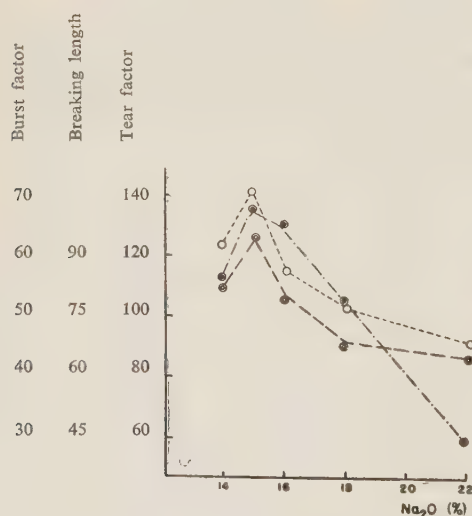


Figure 10  
Influence of amount of alkali used for digestion on the physical characteristics of *E. rostrata* (Hadera) pulp at 150 C.S.F.  
Legend as in Figure 6.

#### *Pulping experiments of E. rostrata from the Negev*

A series of preliminary experimental cooks, carried out with 250 g samples in the small rotary digesters, is summarized in Table VII. It is seen from this table that at 13%  $\text{Na}_2\text{O}$  a screened yield of 48.5% of a pulp with a permanganate number of 25 is obtained. This amount of alkali seems to be sufficient for the digestion of the Negev sample, while for the Hadera sample, other experimental conditions being identical, 15% were necessary (see Table I).

TABLE VII

*Cooking data of E. rostrata from the Negev (Series 1 and 2)*

(Sulphidity 25%, temp. 150°C, cooking time 90+180 min, wood to liquor ratio 1—3, chips handmade)

Cook No.	Alkali (%Na <sub>2</sub> O)	Yield total (%)	Permanga- nate number	Screenings (%)	Residual alkali (g Na <sub>2</sub> O/l)	Alkali consumed (% on wood)
EN 2/0	11	57		almost all	2.2	10.4
EN 2/1	12	55		a great part	2.9	11.1
EN 2/2	13	50	25	1.6	2.9	12.0
EN 2/3	14	48	21	0.4	4.8	12.5
EN 2/4	15	47.5	19.5	0.3	5.2	13.5
EN 2/5	16	47	18.5	almost nil	6.6	14.0
EN 1/3	17	46	18.5	" "	9.5	14.2
EN 1/4	18	44.5	17.5	" "		
EN 1/5	20	44.5	15.8	" "	12.5	16.3

The strength characteristics of some of the Negev pulps beaten in the Lampen mill are reported in Tables VIII and IX and in Figures 11, 12 and 13. While burst, tensile and folding endurance are higher for 13% Na<sub>2</sub>O, the tear factor seems to be higher for the pulp obtained with 15% Na<sub>2</sub>O.

TABLE VIII

*Beating characteristics of E. rostrata (Negev) pulp (Lampen mill)*

Cook No.	No. of revolutions	Canadian freeness (ml)	Tear factor (g)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)
EN 2/2						
13% Na <sub>2</sub> O	10,000	400	95	33	5000	26
	20,000	310	105	57	6900	400
	30,000	210	105	63	8300	900
EN 1/1						
15% Na <sub>2</sub> O	10,000	375	109	32	5400	67
	20,000	200	130	52	6900	230
	30,000	175	117	53	7300	1082
EN 1/4						
18% Na <sub>2</sub> O	10,000	275	74	31	500	10
	20,000	170	75	24	540	24
	30,000	160	79	27	650	28

TABLE IX

*Comparison of the strength characteristics of E. rostrata (Negev) (series 1 and 2) prepared with different Na<sub>2</sub>O amounts at 200 ml Canadian freeness (Lampen mill)*

Cook No.	Alkali (% Na <sub>2</sub> O)	Tear factor (kg)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)
EN 2/2	13	105	63	8400	790
EN 1/1	15	126	53	7100	560
EN 1/4	18	74	26	5100	20

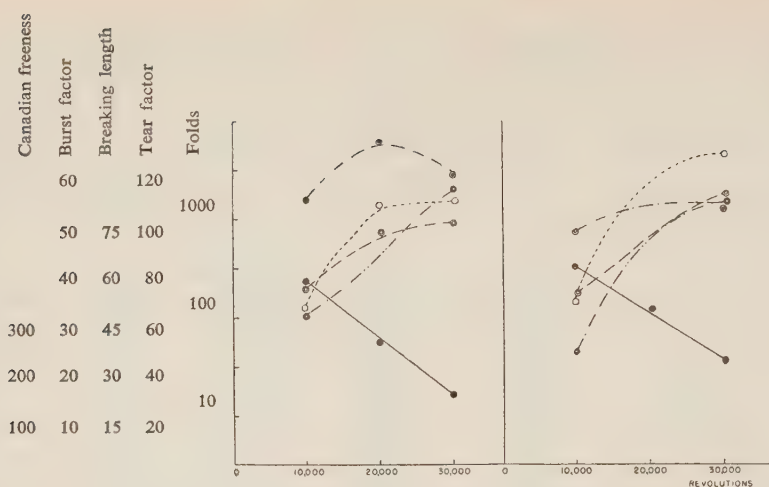


Figure 11  
Beating and strength characteristics of *E. rostrata* (Negev) pulp (LEFT: EN 1/1 — 15% Na<sub>2</sub>O, RIGHT: EN 2/2 — 13% Na<sub>2</sub>O). Legend as in Figure 6.

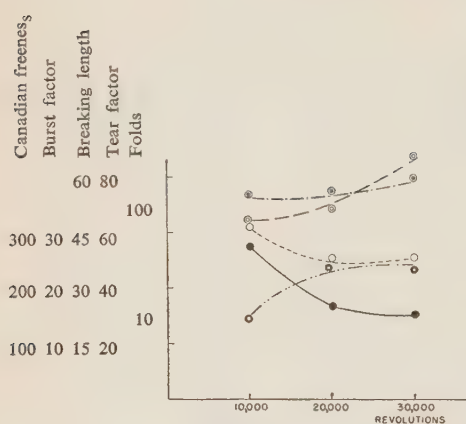


Figure 12  
Beating and strength characteristics of *E. rostrata* (Negev) pulp cooked with 18% Na<sub>2</sub>O (EN 1/4). Legend as in Figure 6.

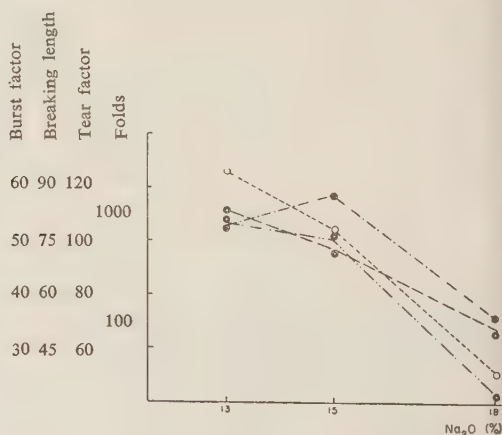


Figure 13  
Influence of amount of alkali used for digestion on the physical characteristics of *E. rostrata* (Negev) pulp. Legend as in Figure 6.

Table X summarizes the strength characteristics of a Negev pulp when beaten in the Valley beater. The pulp was prepared by cooking in the 12 litre digester. The yield obtained was somewhat higher than that obtained in the small digesters (Table VII). In general, the strength values recorded in Table X conform to the values of Table Va for the Hadera pulp, except for the tear factor which seems to be lower for the Negev pulp. The lower tear factor might be due to the lower fibre

length of the Negev sample. The air permeability of the Negev pulp, although still high, is somewhat lower than that of the Hadera pulp.

TABLE X

*Properties of E. rostrata (Negev) sulphate pulp after various beating times (EN 2/2b)*

(Wood chips corresponding to 2000 g oven dry wood, Na<sub>2</sub>O wood 13 %, sulphidity 25 %, temperature 150°C, time 90 + 180 min, yield total 51.5 %, screenings 2.5 %, permanganate number 23)

Beating time (min)	Beating characteristics in Valley Niagara beater					
	Canadian freeness (ml)	Air permeability (sec/100 cm <sup>3</sup> )	Tear factor (g)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)
0	575					
15	460	3	93	36	5300	30
30	235	15	100	55	6700	250
45	150	182	77	66	9000	1100

Comparison of the strength values of the Negev pulp obtained by beating in the Valley beater and by beating in the Lampen mill, the freeness values being the same, shows that the values obtained by the Lampen mill, though still of the same order of magnitude and having the same trend, are higher.

The freeness values were on the whole lower for the Negev pulp than for the Hadera pulp at the same beating times, so that it may be concluded that the Negev pulp is more easily beaten both in the Valley beater and in the Lampen mill.

#### COMPARISON OF COOKING SCHEDULE AND PULP CHARACTERISTICS OF ISRAELI *E. rostrata* PULP TO THOSE OF THE AUSTRALIAN EUCALYPTS AND OTHER HARDWOODS

##### *Cooking variables*

The alkali demand of the Israeli *E. rostrata* is within the range of figures used in Australia (10—18 % Na<sub>2</sub>O). The amount of 13—15 % found in the present investigation conforms closely to the amount used by Australian Paper Manufacturers Ltd., for mixed Eucalyptus species<sup>1</sup>. At A.P.M. higher temperatures and times are applied in the digestion than in the present investigation.

When comparing the alkali demand at the same temperatures and times it was found that the *E. rostrata* can be cooked at mill conditions with less alkali (13.7 %) than the "mixed species" composed of a furnish containing *E. regnans*, *E. obliqua*, *E. sieberiana* and *E. gigantea* (14.5 % Na<sub>2</sub>O).

Since the alkali demand is usually changing with the change in the composition of the furnish, there is a definite advantage in using one species of Eucalyptus having the same alkali demand. The alkali demand for the *E. rostrata* seems to be in the range specified in the literature<sup>10</sup> for digestions of hardwoods by the sulphate process. The times and temperatures required seem to be lower for the *E. rostrata* pulp than for most hardwoods, for which times of 2 + 2 hours at up to 165° are



recommended. It is interesting to note that in a recent investigation on American hardwoods<sup>11</sup> the severe cooking conditions of 19.5% Na<sub>2</sub>O at 175°C and 190+50 minutes were used.

### Yield

The screened yield of unbleached pulp obtained in the present study from *E. rostrata* was in the range of 49—51% of oven dry pulp calculated on oven dry wood. This seems to be in the higher limit of yields specified in the literature for most hardwoods (45—50% of pulp bleachable with 10—12% chlorine to 80—82% G.E. brightness<sup>9</sup>). The commercial screened yield recorded by Jeffreys<sup>1</sup> as obtained at A.P.M. is 47% for "mixed species", while for young *E. regnans* yields of 50—52% have been recorded. The yields recorded by MacLaurin and Peckham<sup>11</sup> on 13 American hardwoods range from 41.5—49.7%. In Table XI the yields of American soft and hardwoods<sup>12</sup> are compared to the yields of the present paper. These authors differentiate between two figures for yields: one describes the yield of oven dry weight of pulp on oven dry weight of wood, which for *E. rostrata* seems to be in the range of the yields usually obtained in the sulphate process. The second figure describes the yield of oven dry pulp per volume of wood, i.e. it takes into consideration the density of the wood. Owing to its comparatively high density, the yields obtained from the *E. rostrata* are among the highest obtained from the hardwoods, and the volume of wood required for the production of one short ton of air dry pulp is 1.35 cords or 4.9 m<sup>3</sup> gross volume (3.45 m<sup>3</sup> solid volume) for the Hadera stand and 1.52 cords or 5.45 m<sup>3</sup> gross volume (3.85 m<sup>3</sup> solid volume) from the Negev variety.

### Strength characteristics

A comparison between the strength characteristics of *E. rostrata* and of the Australian pulps recorded by Jeffreys<sup>1</sup> is difficult. The Australian data were obtained on pulps beaten in the Lampen mill and sheets prepared on a British Standard Sheet Machine, while in the present paper the pulps were beaten in the Valley beater and the sheets made in the Valley sheet machine.

Samples of *E. rostrata* sulphate pulp which have been prepared with 14% of Na<sub>2</sub>O have therefore been beaten in the Research Laboratories of the A.P.M. in the Lampen mill and the properties of the sheets were compared with sheets made at identical conditions from a pulp which was considered the average standard of A.P.M. "mixed species" pulp, except for the tear factor which was 6% above standard. The testing methods and apparatus used were also identical for both samples.

The results of this comparison are summarized in Table XII and Figure 14. It is seen that the general forms of the strength curves are very similar for both pulps, when compared at the same numbers of revolutions. While the breaking length and bursting strength values for both pulps are very close, the tear factor seems

TABLE XI  
Yields of sulphate pulps from various woods

Species	Density moisture free weight per green volume (lb/ft <sup>3</sup> )	Moisture free wood per cord 4 × 4 × 8 ft (lb)	Yield of screened sulphate pulp moisture free per 100 lb of moisture free wood <sup>a</sup> (lb)	Yield of air dry sulphate pulp per cord <sup>b</sup> (lb)	Yield of air dry sulphate pulp per cord <sup>b</sup> (lb)	Wood required per ton (2000 lbs) of pulp moisture free pulp <sup>b</sup> (cords)	air dry pulp <sup>b</sup> (cords)
Softwoods							
Douglas fir <sup>c</sup>	29	2410	48	1085	1205	1.85	1.66
Hemlock eastern <sup>c</sup>	24	1990	45	845	940	2.37	2.13
Black spruce <sup>c</sup>	24	1990	49	920	1020	2.17	1.96
Hardwoods							
Green ash <sup>c</sup>	32	2660	44	1100	1220	1.82	1.64
Aspen <sup>c</sup>	22	1825	56	960	1070	2.08	1.87
Sweet gum <sup>c</sup>	28	2320	50	1090	1210	1.84	1.65
<i>E. rostrata</i> Hadera <sup>d</sup>	34	2820	50.5	1335	1480	1.50	1.35
<i>E. rostrata</i> Negev <sup>d</sup>	31	2570	49	1184	1320	1.69	1.52

<sup>a</sup> As determined by experiment.

<sup>b</sup> Allowing 6% barking, chipping and fibre loss.

<sup>c</sup> Determined by Bray, Shafer and McGovern<sup>12</sup>.

<sup>d</sup> Determined in the present investigation.

TABLE XII

Comparison of Lampen mill beaten Israeli *E. rostrata* (Hadera) sulphate pulp (14% Na<sub>2</sub>O) and A.P.M. Maryvale Mill "mixed species" standard sulphate pulp

Revo- lutions	Canadian freeness (ml)	Tear factor (g)	Breaking length (m)	Burst factor (kg)	Air permeability (sec/100 cm <sup>3</sup> )	Bulk (cm <sup>3</sup> /g)	M.I.T. folds (1 kg tension)
Israeli <i>E. rostrata</i> pulp							
0	395	97	5400	43	6	1.87	11
3750	260	109	8800	63	16	1.63	94
7500	165	116	10300	74	49	1.56	270
10000	155	121	10500	76	63	1.53	366
A.P.M. standard pulp							
0	425	75	5100	28	4.5	1.87	9
5000	330	114	9900	67	40	1.55	141
7500	235	110	10500	75	98	1.51	416
11250	200	106	10800	76	143	1.49	565
15000	150	106	11400	81	505	1.45	1297

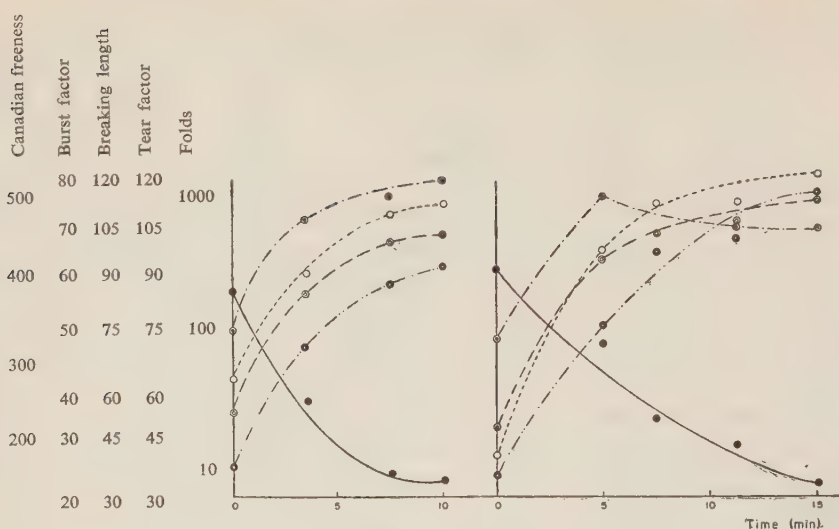


Figure 14

Comparison of Lampen Mill beaten Israeli *E. rostrata* (Hadera) sulphate pulp (14% Na<sub>2</sub>O) with A.P.M. Maryvale Mill "mixed species" standard sulphate pulp. Legend as in Figure 6.

to be higher for the *E. rostrata* pulp. The maximum in the tearing strength curve for the "mixed species" pulp noticed at 5000 revolutions is a highly significant feature and originates from the *E. regnans* in the furnish of the mixed species. This maximum is not found in the *E. rostrata* pulp, for which the tear factor is steadily increasing up to 14000 revolutions. At 7500 revolutions the tear factor (116 g) will be higher by about 12% than the tear factor of the standard A.P.M. pulp (103 g), while the burst factor and breaking length are very nearly the same (103 against 105 kg and 74 against 75 kg for the *E. rostrata* and A.P.M. pulps respectively). The freeness values are generally lower by about 40–60 ml for the *E. rostrata* pulp than for the A.P.M. pulp for the same number of revolutions.

The bulk values and the air permeability seem to be higher for the Israeli pulp, while the folding endurance appears to be lower. The high bulk seems to be an important characteristic of the Israeli pulp. In Table XIIa the bulks of several kinds of pulp from softwoods, hardwoods and straw are compared to the bulk of the Eucalyptus pulps. It is seen that at the same freeness values, the Israeli Eucalyptus pulp has the highest bulk, which might be highly important for the production of printing papers.

The breaking length and bursting strength of the *E. rostrata* sulphate pulps increase with beating, and values of 11000 m and 83 kg respectively were obtained for low freeness values (100), while the tear factor decreased to 80–85. As in the Negev pulp, it is seen that also in this case all strength values (except the double folds) are higher in case of the Lampen mill beating, for the same freeness values

TABLE XII a

*Comparison of bulk (specific volume in cm<sup>3</sup>/g) of the E. rostrata pulp with the bulk of other pulps*

	Australian Eucalyptus <sup>a</sup>	Israeli <i>E.</i> <i>rostrata</i> <sup>c</sup>	Hard- woods <sup>b</sup>	Soft- woods <sup>b</sup>	Straw (soda) <sup>b</sup>	Straw (mono- sulphite) <sup>b</sup>	Straw Celedor <sup>b</sup>
Unbeaten	1.81	1.87	1.65	1.52	1.52	1.82	1.41
(with C.S.F.) (515)	(515)	(395)	(685)	(700)	(500)	(600)	(500)
Valley beaten							
(150 C.S.F.)	137	1.52	1.28	1.36	1.34	1.48	1.24

<sup>a</sup> Quoted from Jeffreys<sup>1</sup>.<sup>b</sup> Quoted from v. Nederveen<sup>13</sup>.<sup>c</sup> Determined in the present investigation.

as in the case of the Valley beating (compare Table IV and Figure 8 to Table XII and Figure 14). On blending *E. rostrata* pulps with slightly beaten softwood sulphate pulp (560 C.S.F.), a satisfactory freeness of 250 — 180 ml could be obtained along with tear values of 137—140 and relatively high values for breaking length and burst. Experiments in this direction will be continued. Such experiments may show to what extent the *E. rostrata* pulp has to be blended in order to obtain strong papers. In Table XIIb, general data are presented for the use of unbleached and bleached Eucalyptus sulphate pulps and their blends, although for *E. rostrata* much more detailed information is still needed and specification requirements must be fixed and compared in this respect.

However, it seems highly probable that *E. rostrata* pulp will be suitable for all uses specified in Table XIIb, either alone or at a high percentage in the required blends.

#### BLEACHING EXPERIMENTS OF *E. rostrata* SULPHATE PULP

Bleaching experiments were undertaken in order to determine the possibility of bleaching the pulps to a reasonable degree of brightness while retaining a high degree of polymerization of the cellulose, and to determine the beating and strength characteristics of the bleached pulps, so as to find out the kinds of white papers which could be manufactured from them.

#### *Experimental*

Two types of bleaching experiments were carried out:

- (1) Of 33 g samples in glass containers.
- (2) Of samples of 450 g performed in enamelled iron containers.

The multistage procedure was adopted in all the experiments. The first stage consisted of chlorination with chlorine water which was added to the suspension of the pulp in water, so that a consistency of 3% was obtained. The entire amount of chlorine was therefore added at the beginning of the chlorination stage.



TABLE XII b  
*Uses of sulphate Eucalyptus pulps*<sup>10,10a</sup>

Kind of paper	Eucalyptus %	In admixture with
Unbleached pulp		
Wrapping 1st strength	20—60	40—80% unbleached coniferous sulphate
Wrapping 2nd strength	60—90	10—40% unbleached coniferous sulphate
Wrapping 3rd strength	100	
Kraft liner boards	20—80	20—80% unbleached coniferous sulphate
Bleached pulp		
Book paper, 1st quality	60—100	
Writing and printing fine papers, 1st quality	90—100	
Rayon and cellophane	100	

The chlorination was carried out at room temperature and continued until almost all the available chlorine (98—99%) was consumed. Usually this lasted 1 hour. After chlorination, the pulp was filtered on a Buchner funnel and washed with tap water. The alkaline extraction stage was carried out with 2% NaOH calculated on oven dry pulp, at a temperature of 70°C, and a consistency of 3% for 1 hour, while stirring with an "S" type glass stirrer. The hypochlorite stage was carried out at a consistency of 3% and with stirring at an initial pH and temperature as described. Calcium hypochlorite was used throughout. Aliquots of solution were withdrawn at definite time intervals and were filtered and titrated with standard thiosulphate solution. The pulp samples remaining on the filter were formed into small sheets and tested for brightness and viscosity. pH determinations were carried out during the hypochlorite stage with a Beckman model pH meter. The brightness measurements were carried out with the Photovolt Brightness Tester, and results were recorded in G.E. units. The viscosity was determined according to the Shirley method (see above) and converted to CP units by means of Tappi conversion chart 113°C.

In the 450 g samples the bleached pulp was beaten in the Valley beater and the strength characteristics determined on sheets prepared from samples of pulp withdrawn from the beater at 15 min intervals.

### Results

#### (1) 3-Stage bleaching (CEH)

In experiment EHB 12, chlorination, alkaline extraction and hypochlorite bleach were carried out. In the chlorination stage 10% of available chlorine calculated on the oven dry weight of the unbleached pulp was used. After 90 min, 98% of the available chlorine was consumed.

Results are summarized in Table XIII.

TABLE XIII

*Yields, permanganate numbers and viscosities after the first 2 stages of Exp. EHB 12*

Stage	Yield (%)	Permanganate number	Viscosity (rhes)	Viscosity (cp)
Unbleached pulp		24	7.5	74
Chlorination (10%) and washing	92	5.7	12.2	35
Alkaline extraction	89	3.7	13.2	31

The above stages were carried out on 100 g pulp. The alkaline extracted pulp was divided into 3 equal parts which were used in 3 different final bleaching experiments. In 2 of these experiments calcium hypochlorite, corresponding to 2% available chlorine, was used at 35°C and 3% consistency. Data on these two experiments are presented in Tables XIV and XV.

TABLE XIV

*Final hypochlorite bleaching of chlorinated and extracted pulp at initial pH = 8.5 (EHB 12a)*  
 (Available Cl 2% on oven dry pulp, consistency 3%, temp. 35°C)

Time (min)	pH	Available Cl (g/l)	Brightness* (% G.E.)	Viscosity (rhes)	Viscosity (cp)
0	8.5	0.56	—	13.27	30
60	8.2	0.25	60	14.72	26
120	8.0	0.21	75	16.61	21
180	7.9	0.18	76	18.73	17
240	7.8	0.16	77*	19.42	15

\* Brightness of the optical sheet formed after thorough washing and acidifying with  $\text{SO}_2=78$ .

Comparison of Tables XIV and XV shows that, while at an initial pH of 8.5 a brightness degree of 78 is obtained after 240 min, at an initial pH of 9.5 a brightness of only 70 G.E. is obtained, the viscosity of both pulps being the same. The final pH was 7.8 in both cases. The consumption of hypochlorite was markedly higher where the initial pH was lower and reached only 70% of the initial concentration.

In a third experiment carried out on the remaining portion of the chlorinated and extracted pulp, 0.186 g of potassium bromide were added corresponding to 0.11 g available chlorine or 0.37% on oven dry pulp. The bromide was added in the form of a dilute solution, 30 min after the commencement of hypochlorite bleaching, at a temperature of 25°C. The results of this experiment (EHB 12/c) are summarized in Table XVI.

It is seen from Table XVI that on addition of bromide to the hypochlorite bleaching stage, although the temperature of the bleaching was reduced to 25°C instead of 35°C, the rate of bleaching was considerably higher, the consumption of the

TABLE XV

*Final hypochlorite bleaching of chlorinated and extracted pulp at initial pH = 9.5 (EHB 13b)*  
(Available Cl 2%, consistency 3%, temp. 35°C)

Time (min)	pH	Available Cl (g/l)	Brightness (% G.E.)	Viscosity (rhes)	Viscosity (cp)
0	9.5	0.56	—	13.27	30
60	8.2	0.25	64	16.51	22
180	8.0	0.21	70	19.31	16
240	7.8	0.20	70	19.45	15

TABLE XVI

*Hypochlorite-bromide bleaching of chlorinated and extracted pulp (EHB 12c)*  
(Available Cl 2%, temperature 25°C, KBr added 0.186 g)

Time (min)	pH	Available Cl (g/l)	Brightness (% G.E.)	Viscosity (rhes)	Viscosity (cp)	Remarks
0	8.5	0.56	—	13.27	30	before addition of KBr
30	8.25		64	14.72	26	
60	8.3	0.25	73			
90	8.15	0.18	72	15.30	24	
120	8.05	0.17	73	16.02	22	
150	8.0	0.16	76	16.04	22	
180	7.8	0.11	77	19.31	16	

hypochlorite was higher and the same degree of brightness was obtained, while the viscosity was not lower than in the corresponding experiments without addition of bromide (see Tables XIV and XV). On addition of the bromide hypobromite is formed<sup>13,14</sup> and a slight increase in pH was observed, which is due to the difference in the dissociation constants of hypochlorous and hypobromous acids<sup>16</sup>.

## (2) 4-Stage bleaching (CHEH)

A number of experiments were carried out in which the bleaching was performed in 4 stages: chlorination, hypochlorite, alkali extraction, final hypochlorite. The pulp used in these experiments was from the same batch as was used in the three stage bleaching experiments, i.e. the permanganate number was 24 and the viscosity (cp) 74.

In a typical experiment, EHB 18, the chlorination was carried out with 9% available chlorine at a 3% consistency for 1 hour. After thorough washing with tap water the pulp was treated with hypochlorite equivalent to 2% available chlorine calculated on oven dry original pulp. The pH was maintained between 8–8.5 by addition of alkali. After 1 hour at room temperature the hypochlorite was exhausted almost completely. After washing with tap water the pulp was extracted with 2%

alkali at 70°C for one hour. The permanganate number of the extracted pulp was 1.5, the viscosity 21 cp and the brightness 40% G.E. The pulp was then submitted to a final hypochlorite bleach with 1% available chlorine at 35°C.

In Table XVII the results of this final bleaching stage are summarized. The results in this table indicate that a higher degree of brightness along with a higher viscosity may be obtained with a four stage bleaching while less chlorine is required in the chlorination stage.

TABLE XVII

*Final hypochlorite bleaching of chlorinated, hypochlorite treated and alkali extracted pulp (EHB 18)*  
(Available Cl 1%, consistency 3%, temp, 35°C)

Time (min)	pH	Available Cl (g/l)	Brightness (% G.E.)	Viscosity	
				(rhes)	(cp)
0	8.5	0.33	40	16.8	21
60	8.0	0.28	75	17.7	18.5
120	7.8	0.26	82	17.5	19.0

The final brightness of optical handsheet after treatment with SO<sub>2</sub> was 83.

In further experiments the amount of chlorine used in the chlorination stage was further reduced to 8%. The permanganate number after the chlorination stage was 5.0.

In the first hypochlorite stage (exp. EHB 19) 2% active chlorine were used and the permanganate number obtained after this stage was 3.0. After the alkaline extraction stage a permanganate number of 1.9 and a viscosity of 55 cp (9.03 rhes) were obtained. 100 g of this pulp were divided in three equal parts and three different final bleaching stages carried out. The results of these treatments are summarized in Tables XVIII, XIX and XX (expts. EHB 19a, EHB 19a, EHB 19b and EHB 19c).

From Table XVIII it is evident that with 1% available chlorine in the final hypochlorite stage a brightness of only 70% G.E. can be obtained at a viscosity of 40 cp. With 2% available chlorine a brightness of 80% G.E. is obtained, with about 25% of the initial hypochlorite still unconsumed. The viscosity of this pulp was 13.9 rhes, a relatively high figure.

Still better results comprising a higher viscosity at the same degree of brightness, are obtained with the addition of potassium bromide at the final hypochlorite stage. The temperature of the treatment in this case is also lower, and the exhaustion of the bleaching agent more complete.

Comparison of the results in Tables XVII and XIX shows that while a higher degree of brightness is obtained in the 4-stage bleach (CHEH) when using 9% available chlorine in the chlorination stage and 1% in the final hypochlorite stage,



TABLE XVIII

*Final hypochlorite bleaching of chlorinated, hypochlorite treated and alkali extracted pulp (EHB 19a)*  
(Available Cl 1%, consistency 3%, temp. 35°C)

Time (min)	pH	Available Cl (g/l)	Brightness (% G.E.)	Viscosity (rhes)	(cp)
0	8.5	0.30		9.03	55
60	7.8	0.13	70		
120	7.5	0.1	70	11.1	40

TABLE XIX

*Final hypochlorite bleaching of chlorinated, hypochlorite treated and alkali extracted pulp (EHB 19b)*  
(Available Cl 2%, consistency 3%, temp. 35°C)

Time (min)	pH	Available Cl (g/l)	Brightness (% C.E.)	Viscosity (rhes)	(cp)
0	8.7	0.60		9.03	55
60	8.5	0.28	72	12.16	35
120	8.1		77	13.02	32
180	8.0	0.17	80	13.9	29

TABLE XX

*Final hypochlorite-bromide bleaching of chlorinated, hypochlorite treated and alkali extracted pulp (EHB 19c)*

(Available Cl 2%, KBr 0.4% on oven dry pulp calc. as act. Cl. The KBr was added 30 min after commencement of bleach and after adjusting the pH to 7. Temp. 25°C, consistency 3%)

Time (min)	pH	Available Cl (g/l)	Brightness (% G.E.)	Viscosity (rhes)	(cp)	Remarks
0	8.7	0.60		9.03	55	
30	7.0					pH adjusted to 7 and KBr added
60	6.5	0.21	74	11.1	40	
120	6.1	0.14	76	12.3	35	
180	6.0	0.12	80	12.66	33	

Brightness of optical sheet after SO<sub>2</sub> treatment was 81.

a markedly higher viscosity is obtained when using only 8% chlorine in the chlorination stage and 2% in the final hypochlorite stage.

In order to determine the change in beating and strength characteristics on bleaching of *E. rostrata* pulp as well as the yield of the bleaching operation, 450 g of pulp were bleached in the 4-stage sequence (CHEH).

The pulp used in these experiments was prepared according to data in Table Va. The permanganate number of the pulp obtained was 28 and the viscosity was 68 cp (7.9 rhes). In the chlorination stage 8% of chlorine were used. In the first hypochlorite stage 2% of available chlorine were used, the time of treatment was 1 hour at 25°C, and the initial and final pH values were 8.5 and 7.5 respectively. The resi-

dual hypochlorite was 6% of the initial amount. The permanganate number after this stage was 3.1 and the viscosity of the pulp was 30 cp (13.3 rhes). It seems that the lower viscosity figure is due to the low pH in the last part of this stage.

After the alkaline extraction stage, carried out as described above, a permanganate number of 1.8 and a viscosity of 28 cp (14 rhes) were obtained.

In the final stage 1.5% of available chlorine were used as hypochlorite. The data of this stage are tabulated in Table XXI. The yield of bleached pulp obtained after the final stage was 89% calculated on oven dry unbleached pulp and 45% on the original oven dry wood.

TABLE XXI  
*Final hypochlorite stage of CHE treated pulp (EH 1/9 cB)*  
(Available Cl 1.5%, consistency 3%, temp. 35°C)

Time (min)	pH	Available Cl (g/l)	Brightness (% G.E.)	Viscosity (rhes)	Viscosity (cp)
0	8.5	0.45		14.0	28
60	8.0	0.30	79	15.0	26
120	7.8	0.25	80	15.1	25
180	7.7	0.22	80	15.8	24

Final brightness: 80% G.E.

In Table XXII and Figure 15 the strength and beating characteristics of the bleached pulp are summarized.

TABLE XXII  
*Properties of bleached E. rostrata sulphate pulp after various beating times (EH 1/9cB)*

Beating time (min)	Canadian freeness (ml)	Bulk (cm <sup>3</sup> /g)	Air permeability (sec)	Tear factor (g)	Burst factor (kg)	Breaking length (m)	Double folds M.I.T. (1 kg tension)	Opacity (%)
0	537	1.8		52	11	2000	1	95.0
15	437		3	80	27	3900	7	93.0
30	300	1.52	7	116	42	5100	33	92.0
45	180	1.47	28	119	57	7200	155	91.5
55	150		90	107	63	8200	800	89.0

Comparison of Table XXII with Table Va as well as Figure 15 shows the differences in the physical properties of the bleached and unbleached pulps. It is seen that the freeness curve of the bleached pulp is flat as compared with the curve of the unbleached pulp. The initial freeness at zero beating time is also much lower for the bleached pulp. This effect may be attributed to the decrease in hemicellulose content due to bleaching. A small change in tear factor is noted, due to the bleaching operation, and at 175 ml C.S.F. the same value was obtained for both pulps. The burst factor and the breaking length dropped only by 5–7% at 150 ml Canadian Standard Freeness. While the folding endurance also decreased, the air

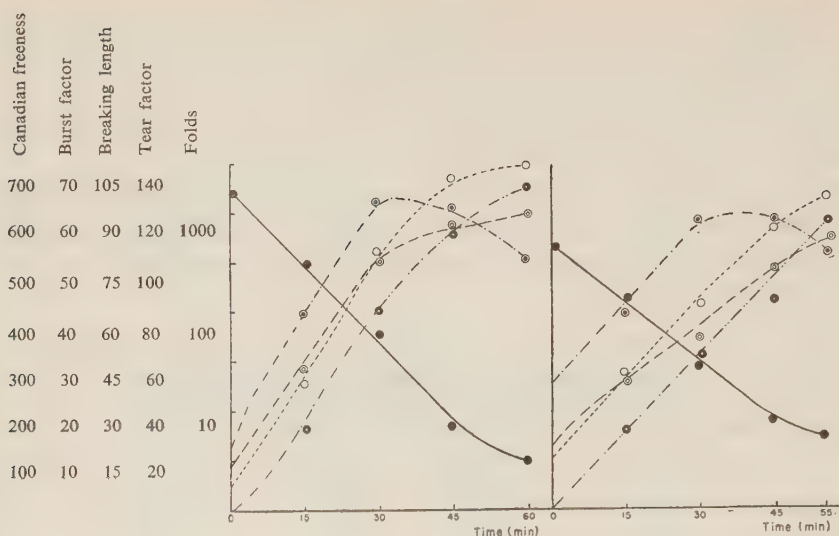


Figure 15

Comparison of strength characteristics of bleached and unbleached *E. rostrata* sulphate pulp at various degrees of beating (LEFT: EH 1/9 c — unbleached, RIGHT: EH 1/9 cB, bleached).

Legend as in Figure 6.

permeability increased. The bulk (specific volume) also decreased somewhat. The opacity values measured seem very high compared to values of commercial papers.

#### DISCUSSION

No investigations have been published on the bleaching of *E. rostrata* pulps, and only isolated data were located concerning bleaching of other eucalypts. Jeffreys<sup>1</sup> mentions that fully bleached commercial eucalypt sulphate pulps have a brightness of 78% G.E. and a loss of strength of 25%, while at special conditions 80–85% G.E. have been obtained in the laboratory. It is evident, therefore, that the Israeli *E. rostrata* is bleachable to the same extent. While no figures are recorded for the chlorine used and the yield of bleached Eucalyptus pulp in Australia in low consistency bleaching, it seems that a consumption of 9.5–12% of chlorine as used in the present study is in the range of the usual chlorine demand of most pulps for the same permanganate number. It does not seem feasible to cook the *E. rostrata* pulp to a much lower permanganate number since the yield, the viscosity and the strength values will decrease.

Cooking the *E. rostrata* wood to a permanganate number of 14 yielded only 41.6% of screened unbleached pulp. It was found by McLaurin and Peckham<sup>11</sup> that in the case of 13 American hardwood sulphate pulps of permanganate numbers in the range of 10–16, the yields of bleached pulps were 85–95%. If an average yield of 90% was assumed for the *E. rostrata* pulp of permanganate number of 14,

a yield of bleached pulp of only 36.6% could be expected. Since the original pulp had a viscosity of 33 cp (12.5 rhes) the bleached pulp would have a much lower viscosity figure and correspondingly lower strength figures. It is possible, however, that pulps with permanganate numbers of 16—20 might be suitable for bleaching, especially when considering cost relationships. This point has to be investigated further.

The loss in weight during the bleaching of the pulps in the present investigation seems relatively low (11% of the unbleached pulp, permanganate number 28) compared with the figures recorded for American hardwoods<sup>11</sup>.

In Table XXIII the viscosity and brightness values obtained in the present investigation are compared with values given by Hatch<sup>17</sup> for hypochlorite bleaching of American sulphate pulps. It is seen from the table that the viscosity of the *E. rostrata* bleached pulp is comparable to that of other experimental bleachings.

TABLE XXIII

*Comparison of brightness and viscosity data of bleached sulphate pulp of the Israeli E. rostrata and American Douglas Fir and Southern Pine*

	Israeli	<i>E. rostrata</i>	Douglas Fir <sup>17</sup>	Southern Pine <sup>17</sup>
Unbleached pulp				
Permanganate number	28	24	17.7	17.55
Viscosity (cp)	68	74	53.7	58.0
Bleached pulp				
Chlorine used (%)	11.5	12	7.4	6.75
Viscosity (cp)	24	29	13.7	22.2
Brightness (% G.E.)	80	80	82.3	79.7

The change in strength properties of the *E. rostrata* pulp on bleaching seems to be small compared to the changes found on American hardwoods<sup>11</sup>. Of special interest seem the high opacity values obtained on the Eucalyptus bleached sulphate pulp which changed from 95% to 89% on beating. The values recorded on the bleached American hardwood pulps never exceed 80%. This property of the *E. rostrata* pulp seems to be in accordance with the high bulk of the pulps which also changed only slightly in the bleaching operation.

The trials on bleaching *E. rostrata* sulphate pulp with the addition of bromide are of preliminary nature only. However, they indicate that the application of bromides is possible in the case of *E. rostrata* sulphate pulps. The advantages found previously<sup>18,19,20</sup> with respect to other pulps when adding bromide are also found in the present investigation. The temperature of the hypochlorite stage can be considerably lowered, the alkali consumption reduced, the rate of bleaching increased, and a higher consumption of available chlorine achieved. It seems also that higher viscosities may be obtained.

The present results on bleaching of *E. rostrata* sulphate pulps should be considered as being merely preliminary. It is possible that an increase in the number



of stages and a redistribution of the applied chlorine between the various stages will lead to improved results and higher brightnesses.

There seems to be no doubt that the Israeli *E. rostrata* sulphate pulps can be successfully bleached and first quality printing and fine papers produced from them. A comparison of the strength and porosity data of these pulps to the properties of commercial bleached writing and printing papers, as used in Israel and determined in this laboratory, showed that *E. rostrata* pulps were of a higher quality (see Table XXIV), even when considering that the strength values of machine-made papers are generally lower than the values of handsheets made from the same pulp.

TABLE XXIV

Comparison of properties of Israeli *E. rostrata* bleached sulphate (150 C.S.F.) with commercial writing and printing papers

Kind of paper	Bright- ness	Burst factor	Breaking length		Folding endurance M.I.T.		Tear factor		Air permea- bility
	(%G.E.)	(kg)	(m)		(1 kg tension)		(g)		(sec)
			Machine direction	Cross direction	M.D.	C.D.	M.D.	C.D.	
Israeli <i>E. rostrata</i> bleached sulphate pulp at 240 ml C.S.F.	80	50	6200		90		106		00
Wood free Scandinavian writing	78	18	3100	2400	9	7	60	69	53
Wood free Hadera writing	76	26	5400	3000	36	25	92	100	21
Wood free Hadera writing	76	22	4900	2700	6	7	90	100	60
Wood free foreign printing	79	16	2700	2300	8	3	53	64	62
Wood free Hadera	77	15	2700	1700	9	4	71	96	12

It is expected that brightness values of 78% G.E. may be obtained on papers produced commercially from the present pulp.

#### CONCLUSIONS AND SUMMARY

(1) It is shown that Israeli *E. rostrata* wood can be successfully cooked by the sulphate method. At a wood liquor ratio of 1:3 or 1:3.4, temperature of 150–160°C, 14–15% Na<sub>2</sub>O and 25% sulphidity and time for reaching temperature of 90 min, a time range of 90–180 min is necessary in order to get easily disintegratable pulp of permanganate numbers 22–28.

(2) The screened yield of unbleached sulphate pulp obtained is in the range of 50–51% oven dry pulp on oven dry wood. When taking into consideration the density of the wood, 34 lb/ft<sup>3</sup> (0.54 g/cm<sup>3</sup>), this yield is among the highest yields obtained from the hardwoods and 1.35 cords or 4.9 m<sup>3</sup> gross volume (3.45 m<sup>3</sup> solid volume) are required for the production of a short ton of unbleached pulp.

(3) With decrease in initial alkali from 22 to 15% Na<sub>2</sub>O the screened yield increases from 41.6 to 51%, the viscosity of the pulp from 33 to 71 cp, the permanganate number from 14 to 26, the residual lignin from 2.5 to 6.1%, while the consumption of alkali decreases.

(4) When considering the viscosity values of the pulps as well as the yield, it seems advantageous to cook the pulp to a permanganate number of 22–26.

(5) The strength values of the *E. rostrata* sulphate pulps increase with decrease in alkali consumed on cooking, the optimum amount of alkali being 15% Na<sub>2</sub>O at 160°C. The pulps cooked with lower amounts of alkali are more easily beaten and shorter times are necessary to obtain required freeness values.

(6) On pulps of permanganate numbers 23–27 prepared with 15% Na<sub>2</sub>O at 160°C tear factors of 130–140 g, burst factors of up to 83 kg, breaking lengths of up to 11,000 m and folding endurance values of above 5000 M.I.T. folds have been recorded. The burst factor, breaking length and folding endurance increase steadily with increasing beating time, while the tear factor starts to decrease only at freeness values lower than 150 ml C.S.F.

(7) The bulk of *E. rostrata* pulps is high compared to other pulps and decreases from 1.87 cm<sup>3</sup>/g in the unbeaten state to 1.52 cm<sup>3</sup>/g at 150 ml C.S.F. The air permeability is correspondingly high.

(8) The cooking conditions for *E. rostrata* are more favourable regarding the cost of production than those of most hardwoods and softwoods used today in the pulp and paper industry.

(9) The *E. rostrata* sample from the Negev is more easily digestible than the Hadera sample and only 13% Na<sub>2</sub>O and a temperature of 150°C are necessary for obtaining a satisfactory pulp with a permanganate number of 23 and a screened yield of 49%. The Negev pulp is more easily beaten than the Hadera pulp. The strength characteristics are generally similar for both pulps with the exception of the tear factor which is lower for the Negev pulp. The bulk and air permeability of the Negev pulp, although still high, are somewhat lower than those of the Hadera pulp.

(10) The relatively high bulk makes the *E. rostrata* pulps particularly suitable for the production of printing papers. The unbleached sulphate pulp from Israeli *E. rostrata* can be used for production of all kinds of wrapping papers with suitable admixtures of unbleached coniferous sulphate pulp.

(11) No difficulties were encountered in the bleaching of Israeli *E. rostrata* pulps.

(12) When bleaching in 3 stages, chlorination (10% available Cl), alkaline extraction and hypochlorite (2% available Cl), pulps with a brightness of 78% G.E. can be

obtained having a Tappi viscosity of 15 cp. The final hypochlorite stage should be carried out at a pH of 8.5–8.0. Work at higher pH values results in lower brightnesses.

(13) On bleaching in 4 stages, chlorination (8% available Cl), hypochlorite (2%), alkaline extraction (2%, 70°C) and final hypochlorite (2% available Cl), pulps having brightnesses of 80–81% G.E. with viscosities of 29 cp can be obtained.

(14) When bleaching in 4 stages, chlorination (9% available Cl), hypochlorite (2% available Cl), alkaline extraction and final hypochlorite (1% available Cl), brightnesses of 82–83% G.E. with viscosities of 19 cp are obtained.

(15) The amount of available chlorine necessary for a full bleach of the Israeli *E. rostrata* sulphate pulps is 11–12% calculated on the oven dry Hadera pulp. Preliminary experiments on bleaching of the Negev pulp show this amount to be in the range of 10%.

(16) It may be expected that a redistribution of the chlorine used among the bleaching stages, a change in the sequence of the stages or an increase in the number of stages will result in considerably higher brightness with higher viscosities and a lowering in the chlorine consumption. This has to be investigated further.

(17) By addition of bromides in the last hypochlorite stage the temperature of treatment may be lowered, the rate of bleaching increased, the alkali consumption decreased and a better exhaustion of the available chlorine may be achieved. Higher viscosities at the same brightness may also be obtained.

(18) The loss in weight during the bleaching of pulps with permanganate numbers of 23–28 is low and amounts to 11% calculated on the oven-dry unbleached pulp so that 45% of bleached pulp with a brightness of 80–83% G.E. calculated on the oven dry wood are obtained.

(19) The beating and strength characteristics of the bleached Israeli *E. rostrata* pulps are only slightly different from those of the unbleached pulps. The burst factor and breaking length decrease only about 5–7% on bleaching.

(20) The bulk of the pulp decreases slightly and the air permeability increases on bleaching. The opacity of the bleached pulps seems high compared to other pulps.

(21) There appears to be no doubt that the Israeli *E. rostrata* sulphate pulps can be successfully bleached and that first quality printing and fine papers can be produced from the bleached pulps.

(22) On comparing *E. rostrata* grown in Israel to other hardwoods it is evident that as far as technical production data, pulp qualities and paper grades are concerned, this species is at least not inferior and even in several respects superior to the hardwoods.

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## APPENDIX I

*Definitions and units used in the present investigation for measuring strength characteristic.*

Basic weight	g/m <sup>2</sup> , g of oven dry substance per m <sup>2</sup> of the handsheets.
Burst factor (Mullen)	Bursting pressure in g/cm <sup>2</sup> divided by basic weight of paper sheet.
Breaking length in metres	200,000/3 × force in kg to break a strip 15 mm wide and divided by the basic weight of paper sheet.
Tear factor (Elmendorf)	Force in g to tear a single sheet × 100 basic weight.
Double folds (M.I.T.)	Number of double folds necessary to break a strip 15 mm wide under a tension of 1 kg in the M.I.T. apparatus.
Bulk (apparent specific volume)	cm <sup>3</sup> /g; reciprocal apparent specific gravity.
Brightness	Percentage of light reflected measured with specified filter in the Photovolt apparatus, reflectivity of MgO being assumed as 100% corresponding to General Electric units.
Air permeability	Time in sec necessary to pass 100 cm <sup>3</sup> of air in the Gurley apparatus.

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## SOME CONCLUSIONS FROM QUALITY CONTROL OF CONCRETE

R. SHALON

*Building Research Station, Technion — Israel Institute of Technology, Haifa*

### ABSTRACT

The object of the investigation was the determination of the relative magnitude of the various factors governing the variability of concrete in actual construction work, with a view to improving its quality and reducing its cost. Plain concrete used for foundations, plinths and walls, and reinforced concrete used for slabs and beams in eight large housing projects were studied.

The results indicate that, listed in order of magnitude, the causes of the variability of the concrete are as follows: (i) use of unmeasured quantities of mixing water, (ii) fluctuations in grading of the coarse aggregate, (iii) variation of the proportions of fine and coarse aggregate as a result of volume-batching, (iv) volume-batching of cement, (v) fluctuations in grading of the fine aggregate\*.

The conclusion reached was that by practicable quality control both a considerable reduction of the cement content and an improvement of the quality of concrete could be achieved. Calculations show that the present quality could be maintained with an average reduction of 20 to 25% in the cement content.

On the basis of the data established in this investigation, and other data obtained by research on the corrosion of reinforcement, a revision of the standard specifications which require a minimum cement content is advocated.

### INTRODUCTION

Concrete is the principal building material in Israel. Plain and reinforced concrete is used in most of the building projects in the country, as well as in the manufacture of numerous concrete products in factories. In 1954, some 450,000 tons of cement were marketed in the country, and it is estimated that 1,850,000 m<sup>3</sup> of concrete were cast.

Comparing the quality of locally produced concrete with that of other technologically advanced countries, its relatively low standard cannot fail to be noted. Hence the need for determining the causes of the disproportion observed between the strength of the concrete and its cement content.

The results presented in this paper were obtained by study of plain concrete used for foundations, plinths and walls, and reinforced concrete used for beams and slabs. The investigation was conducted mainly in the northern part of the country, at six

\* It was found, however, that in some instances the order of the last two causes was reversed.

major building projects, and on a smaller scale in the central district, at two more projects. The construction work was carried out by five different contractors' firms.

The objects of the research were: (i) determination of the quality of the concrete produced at the projects, and its statistical analysis, (ii) evaluation of the factors governing the variation of quality, (iii) determination of the cement content required for ensuring a minimum selected strength, both under present local production methods and under improved control conditions.

The effect of the following factors was studied in tests of over 2000 specimens:

1. Batching of the cement by volume, instead of by weight.
2. Fluctuations in aggregate grading.
3. Volume-batching of aggregates (as opposed to weight-batching).
4. Addition of the mixing water by eye-estimate instead of by measure.

## MATERIALS

### *Cement*

"S" cement (selectively ground) produced by the Nesher Portland Cement Works of Israel, was used for the plain concrete mixes. The cement is made by intimately mixing together suitably burnt Portland cement clinker of particle size<sup>1</sup> not larger than 40 microns with both calcareous and siliceous inert material suitably graded in the particle-size range of 40—200 microns. The average mechanical properties of this cement are given in Table I.

TABLE I  
*Properties of "S" cement*

Fineness	Residue on B.S. sieve No. 170 (Size of aperture 0.089 mm) — 7%
Setting time (Vicat)	Initial — 2 hrs 45 min. Final — 4 hrs 30 min
Soundness test (Le Chatelier apparatus)	0.5 mm
Crushing strength <sup>2</sup> (standard concrete)	At 3 days — 113 kg/cm <sup>2</sup> . At 7 days — 156 kg/cm <sup>2</sup>

"Nesher" Portland cement was used for the reinforced concrete mixes. The average mechanical properties of this cement are given in Table II.

TABLE II  
*Properties of "Nesher" Portland cement*

Fineness	Residue on B.S. sieve No 170 — 6.2%
Setting time (Vicat)	Initial — 2 hrs 50 min. Final — 4 hrs 10 min
Soundness test (Le Chatelier apparatus)	1.0 mm
Crushing strength <sup>3</sup> (standard concrete)	At 3 days — 136 kg/cm <sup>2</sup> . At 7 days — 200 kg/cm <sup>2</sup>

*Aggregate*

The coarse aggregate was crushed dolomitic limestone. The fine aggregate was natural sand. The properties of the aggregates are given in Table III.

TABLE III  
*Properties of aggregates*

Chemical composition (%)						
	Crushed stone			Sand		
CaCO <sub>3</sub>	63.2			81.0		
MgCO <sub>3</sub>	33.6			8.0		
SiO <sub>2</sub>	2.1			3.5		
Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub>	1.1			7.5		
NaCl	Traces			Traces		
Mechanical analysis						
Percent retained						
Sieve size	Crushed stone			Sand		
(B.S. sieves)	Project A	Project D	Projects E and F	Project A	Project D	Projects E and F
1½"	0—7	0—38	0			
¾"	3—95	2—97	22—100			
⅜"	22—100	65—100	85—100			
3/16"	83—100	95—100	99—100			
No. 7	85—100	99—100	100		0—5	0—2
No. 14	98—100	100		0—5	1—7	0—3
No. 25	100			5—26	6—23	4—8
No. 52				79—93	84—98	71—99
No.100				96—100	100	100
Fineness modulus	6.21—8.02	6.63—8.19	7.06—8.00	1.85—2.24	1.96—2.31	1.77—2.08
Average fineness modulus	7.18	7.60	7.75	1.99	2.09	1.97
Unit weight kg per m <sup>3</sup>	1.30	1.31	1.30	1.41	1.42	1.43

The exceptionally wide fluctuation in the grading of the coarse aggregate will be discussed later.



## TEST PROCEDURE

The crushing strength of the concrete was determined by tests of 12 cm cubes, in accordance with the Israel Standard Specification<sup>4</sup>. Site-produced concrete was taken from the mixer and cast into test specimens, compacted and cured according to standard specifications. Thus, the crushing strength of these test specimens represents the potential strength of the concrete in the structure, and serves as a yardstick for its quality in general.

The samples were taken on different days and at different times of the day. From each sample, 3–6 cubes were cast, demoulded after 24 hours and cured for 6 days in a moisture room. Some of them were then tested (at 7 days) and the rest were kept for 21 more days in the laboratory and tested at 28 days.

The correlation coefficient for each set of three cubes was found to be  $r = 0.95$  (with very few exceptions). Hence, the mean of three cubes represents the strength of the sample with adequate accuracy.

The water content was determined for 51 samples of fresh concrete. The method consisted of weighing the sample, rapid drying and reweighing, the loss in weight giving the mixing water content. A procedure ensuring a high degree of accuracy was worked out in preliminary experiments at the Building Research Station of the Technion.

## TEST RESULTS

The specifications of the concrete mixes are given in Table IV.

TABLE IV  
Concrete mixes

	Fine-to-coarse aggregate ratio by volume	Cement content (kg/m <sup>3</sup> )	Water/cement ratio by weight	Minimum strength required at 28 days (kg/cm <sup>2</sup> )
<i>Plain concrete</i>				
Project A	40% sand 60% coarse	220	not specified	60
<i>Reinforced concrete</i>				
Project D	40% sand 60% coarse	280	not specified	120
Project E	"	300	0.77	120
Project F	"	300	0.77	120
Project G	unknown	300	not specified	120
Project H	unknown	300	not specified	120

*Plain concrete*

Figure 1 shows the results of crushing tests for Project A, and Figure 2 the corresponding histogram, from which the following data were obtained:

Average strength	— 68 kg/cm <sup>2</sup>	Standard deviation	— 16 kg/cm <sup>2</sup>
Minimum strength	— 41 kg/cm <sup>2</sup>	Coefficient of	
Maximum strength	— 107 kg/cm <sup>2</sup>	variation	— 23.5 %

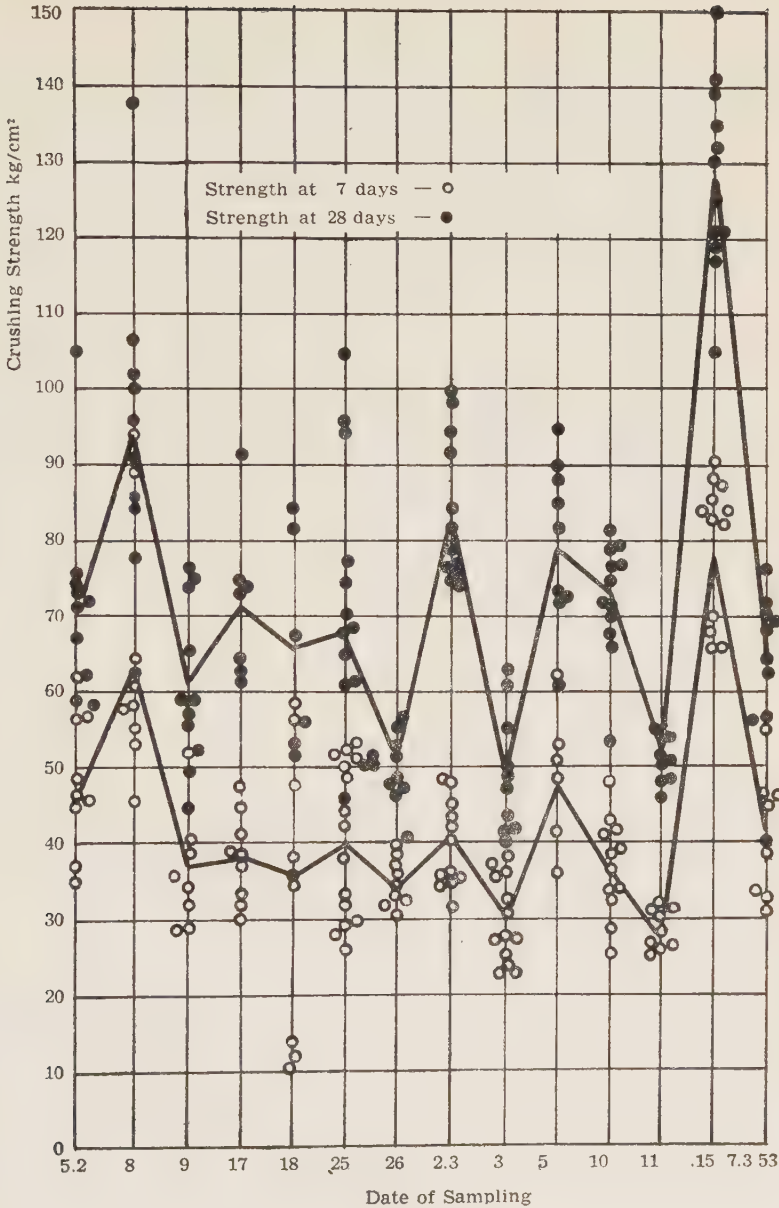


Figure 1  
Crushing strength of concrete at Project A.

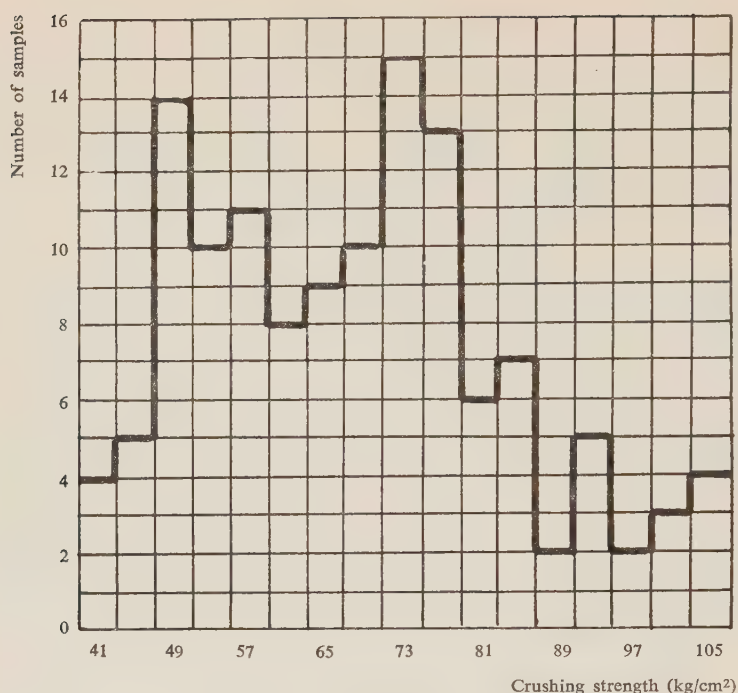


Figure 2  
Histogram of concrete at Project A.

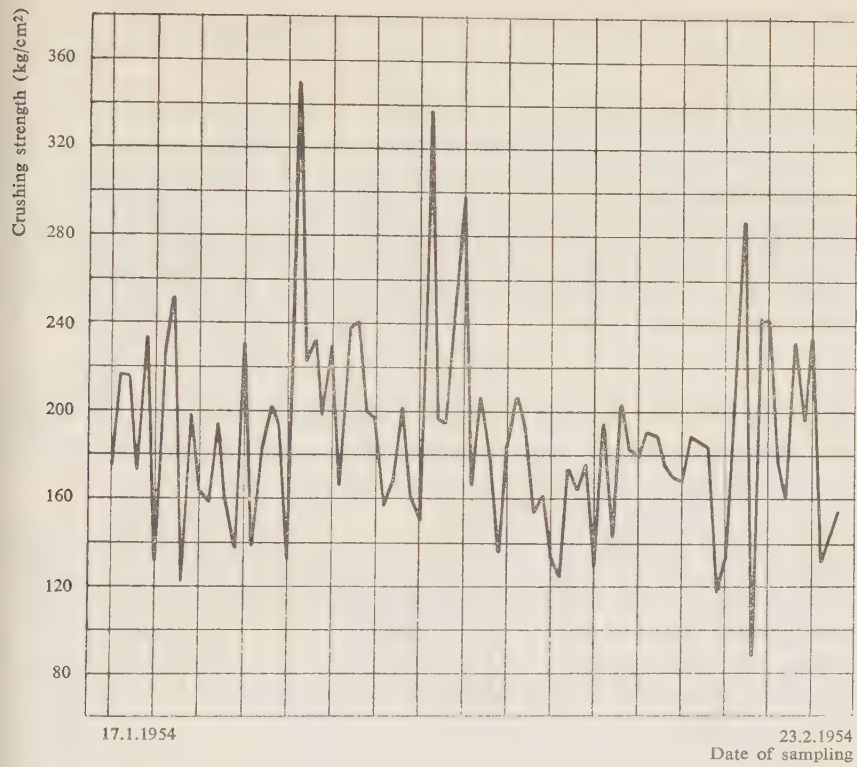
### *Reinforced concrete*

Crushing tests results and statistical analysis are summarized in Table V.

TABLE V  
*Results of compressive tests*

Project	Average strength (kg/cm <sup>2</sup> )	Minimum strength (%)	Minimum strength (kg/cm <sup>2</sup> )	Maximum strength (%)	Maximum strength (kg/cm <sup>2</sup> )	Standard deviation (kg/cm <sup>2</sup> )	Coeff. of variation (%)	Percentage of samples below minimum strength
D	187.4	100	84	45	362	193	44.3	1
E	197.4	100	105	53	272	183	43.0	1
F	250.3	100	170	68	326	130	35.6	0
G	208.0	100	74	36	356	171	68.4	9
H	156.0	100	74	47	252	141	32.3	7

Figures 3 and 4 give, respectively, the strength diagram and corresponding histogram for Project D — very typical for local concrete.





## EVALUATION OF THE FACTORS GOVERNING THE VARIATION OF STRENGTH

*Cement*

- (i) In most cases, volume-batching of the cement was found to cause fluctuations of  $\pm 10\%$  in the cement content, and in single cases — as high as  $\pm 24\%$ .
- (ii) The overall variation of the cement content between batches is dependent, in addition to the above, on the fluctuation in grading and in quantity of the aggregates, and to a lesser extent also on the fluctuation in consistency. The overall variation was generally found within the limits of  $\pm 14\%$ , and in some cases  $\pm 20\%$ .

*Aggregates*

- (i) The grading of the fine aggregate, given in Table III, was found to vary within not too wide limits. Most of the sand was of a size between B.S. sieves No. 25 and 100 (aperture size 0.15—0.60 mm), i.e. too fine.
- (ii) The grading of the coarse aggregate, on the other hand, was found to vary out of all proportion. Aggregate ordered and supposedly supplied as "Fulieh" (as specified by I.S.S. No. 3)<sup>5</sup> often consisted of random consignments of "Adasieh" and "Jozieh"<sup>5</sup> of a maximum size ranging from  $3/4''$  to  $3''$  and fineness moduli from 6.2 to 8.0 (Project A) and from 6.6 to 8.2 (Project D). At Projects E and F, however, all of the coarse aggregate had a maximum size of  $1\frac{1}{2}''$  and fineness moduli ranged from 7.1 to 8.0.

Figure 5 illustrates the extreme variability of the coarse aggregate at Project D.

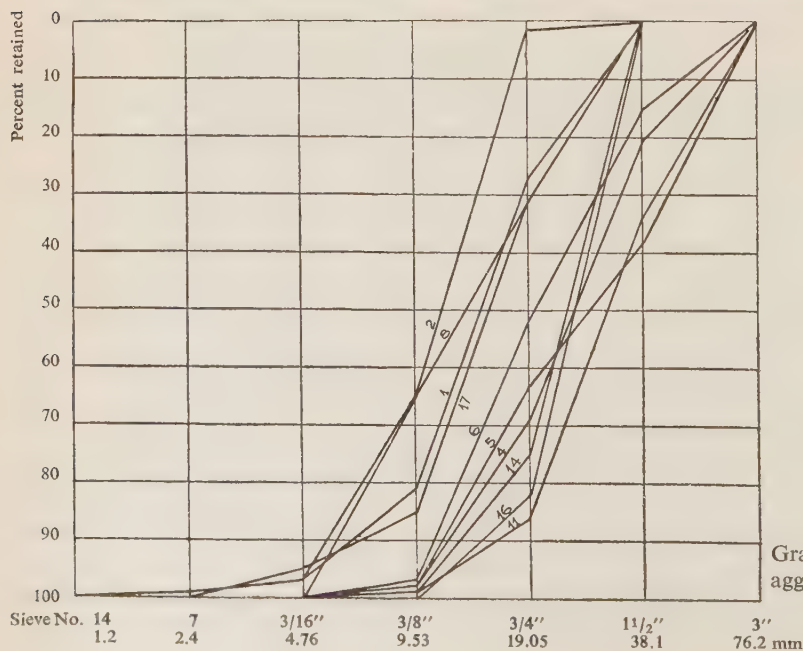


Figure 5  
Grading of coarse  
aggregate at Project D.

- (iii) In keeping with local practice, the aggregates were measured by barrow-loads. Figures 6 and 7 show the respective histograms of the actual weights of fine and coarse aggregates. This method of volume-batching resulted in widely varied fine-to-coarse ratios, ranging from 38/62 to 50/50 by weight, instead of the specified 40/60 by volume, corresponding to 42/58 by weight.
- (iv) The above mentioned fluctuations in grading (particularly of the coarse aggregate) and in quantity of aggregate used, resulted, in turn, in a considerable variability in mix proportions. Table VI shows the variations of fineness moduli at the different projects, and the corresponding variations of strength which would result from them.

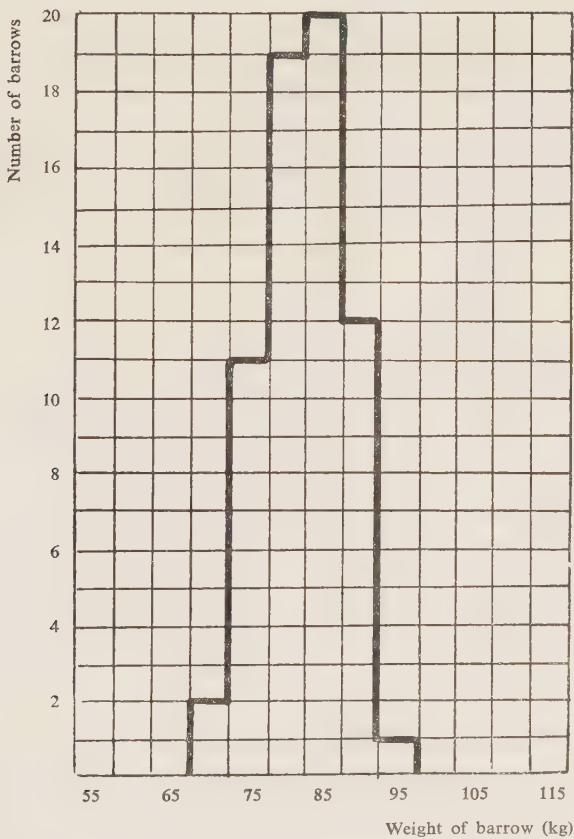


Figure 6  
Histogram of fine aggregate weights.

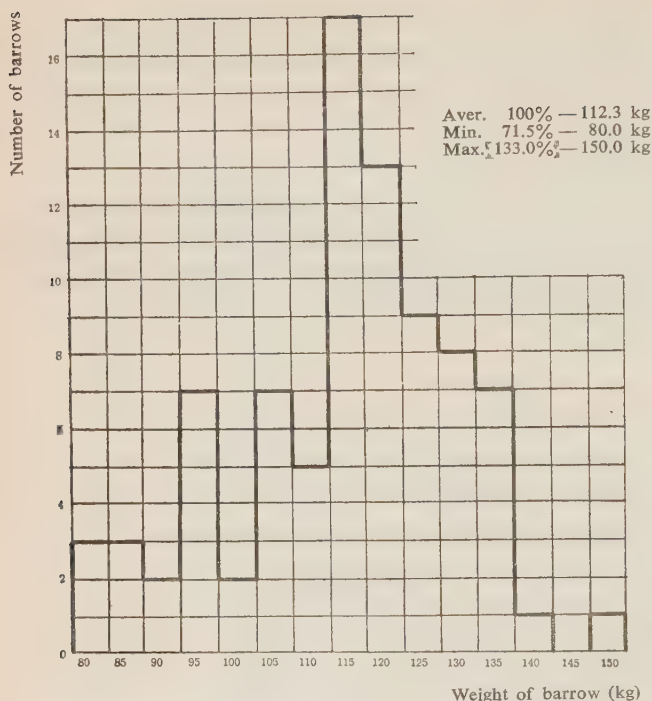


Figure 7  
Histogram of coarse aggregate weights.

TABLE VI  
*Influence of the variation of aggregate grading upon strength*

Project	A	D	E and F
Range of variation of aggregate (fineness moduli)	4.03—5.82	4.30—5.92	4.42—5.75
Corresponding range of variation of strength (%)	100—210	100—185	100—170

### *Mixing water*

The water/cement ratio was specified for two of the projects only (E and F), and only at one project was a water-meter actually used (accuracy  $\pm 6\%$ ). At all other (seven) projects, the quantities added were estimated by eye, in keeping with the local practice.

The water content of mixes prepared during a single day at Project D was determined by analysis of 22 samples. The variation of the water content is shown in Figure 8. It ranges from 176 to 376 l/m<sup>3</sup>, which corresponds to a variation of the water/cement ratio from 0.63 to 1.34 (provided the moisture content of the aggregates and the cement content remain constant).

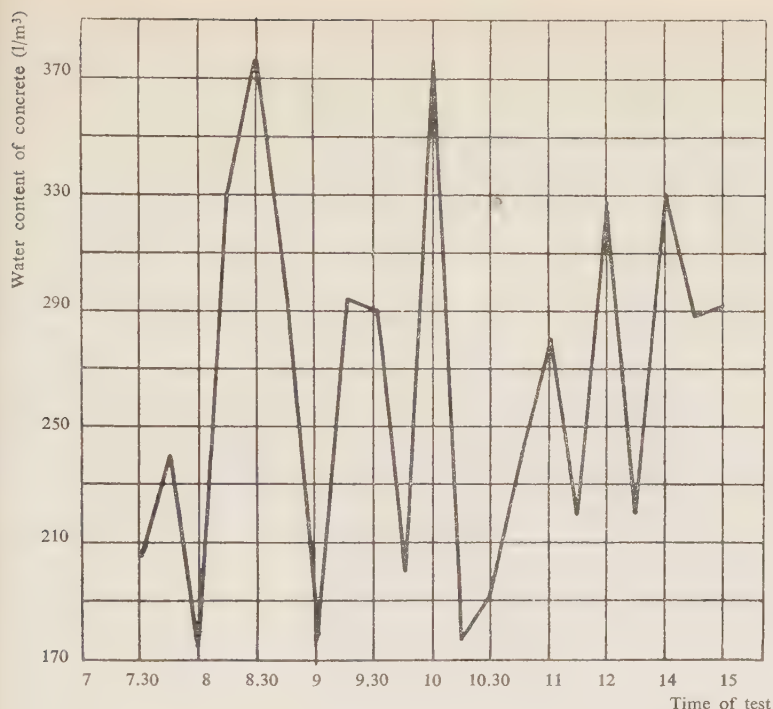


Figure 8  
Water content at  
Project D.

A similar picture could be observed at Project A, where 29 samples were taken at different times of the day for 4 days (see Figure 9). Here, the water content was found to range from 175 to 380 l/m<sup>3</sup>.

Laboratory experiments, in which concrete mixes were prepared under conditions identical with those prevailing at the building site, showed that the extreme variability of the water content was not due to fluctuation in the dry mixes alone, but that the consistency of the concrete was also highly variable. At Project F, a water-meter was used, with no allowance made for aggregate moisture. In spite of the variability of mix proportions mentioned above, the quantity of water remained unchanged. This was possibly due to the fact that the concrete, though variable, was still workable.

#### DISCUSSION

The data obtained in the investigation showed that the coefficient of variation for local concrete is approximately 23%. The deviations found for Projects E ( $v = 21.8\%$ ) and H ( $v = 20.6\%$ ) are not significant. By the Stanton Walker rating<sup>6</sup> the average local concrete would be classified as bad; only in the case of Project F ( $v = 14.2\%$ ) it can be rated as good, while for Project G (32.8%) it would be rated as very bad.

Listed in order of magnitude, the causes of this low quality are: (i) use of unmeasured quantities of mixing water, (ii) fluctuation in grading of the coarse aggregate, (iii) volume



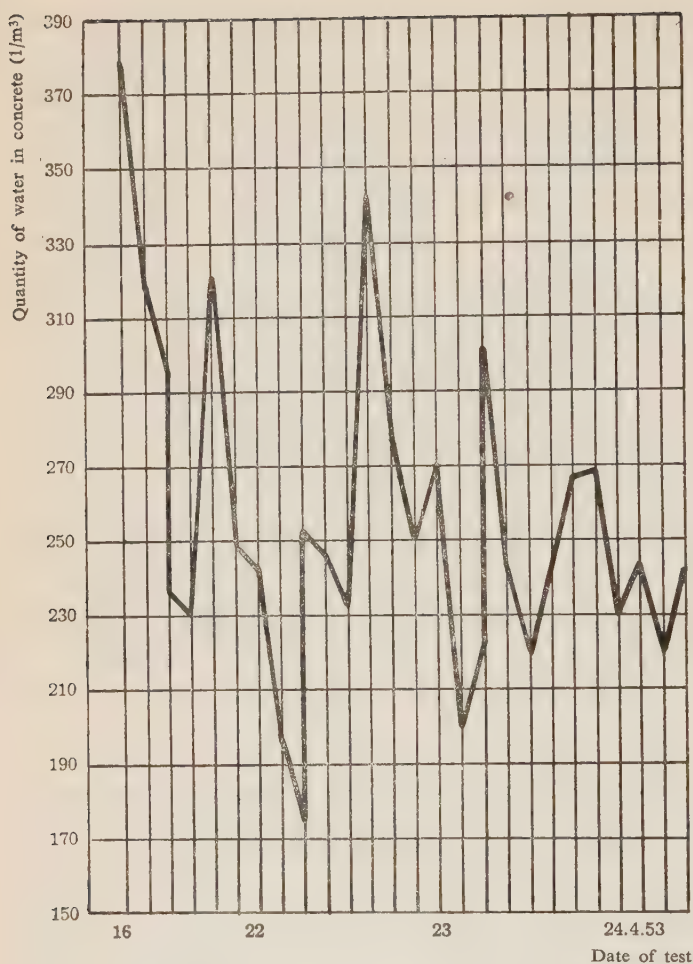


Figure 9  
Quantity of mixing water at  
Project A.

batching of the aggregate, (iv) volume batching of the cement, and (v) fluctuation in grading of the fine aggregate. (It was found, however, that in some instances the order of the last two causes was reversed.)

#### *Mixing water*

The fluctuations in water content at Project D, which resulted in a water/cement ratio ranging from 0.63 to 1.34, cause a variation of strength from 68 to 325 kg/cm<sup>2</sup>, very close to the respective minimum and maximum found in crushing tests of site samples taken at random. In the case of widely variable aggregate, it is obviously impossible to specify a fixed water content, but in cases of moderate variability, such as at Project F, fairly narrow limits can be set, even when the aggregates and cement are batched by volume. The resulting improvement can be seen from Figure 10, showing

the average strengths at Projects E and F, which were both built by the same contractor under identical conditions, the only difference being that in one of them the water was added by measure. The coefficient of variation in Project E was 21.8 %, while in Project F it was 14.2 % — a statistically significant difference, designating them respectively as “bad” and “good” by the Stanton Walker rating. Where the variability of grading, method of batching etc. preclude the specification of a fixed water content, a maximum limit must be set.

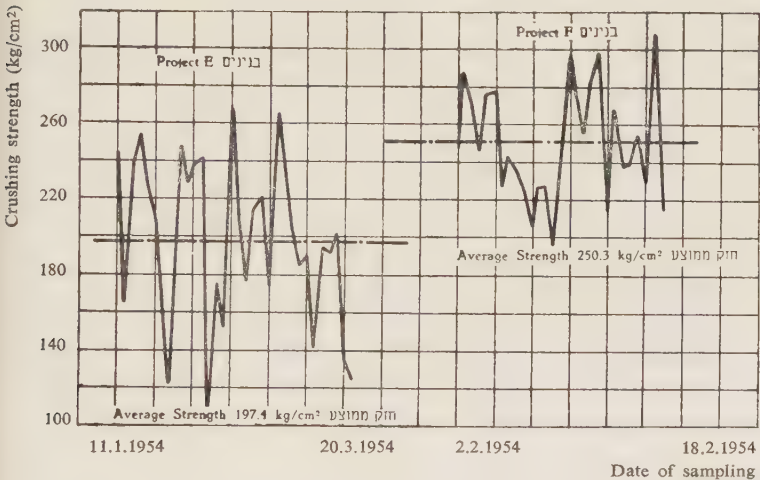


Figure 10  
Effect of measuring  
the mixing water on  
strength of concrete.

It is worth while to emphasize here that the maintenance of a specified consistency, as determined by the slump test, cannot provide a substitute for measuring the water, especially under the conditions in question. Apart from the fact that the slump is liable to vary even for identical concretes, an earlier investigation by the author proved that the fluctuations of aggregate grading and those of the mix proportions resulting from volume batching render the slump test practically valueless<sup>7</sup>.

*Fluctuation of aggregate grading and mix proportions*

The variability of the maximum size and of the grading of the coarse aggregate at Projects A and D resulted, as mentioned above, in considerable variability of the mix proportions. Combined with volume batching, it resulted in fineness moduli ranging from 4.22 to 5.82 at Project A, and from 4.36 to 5.87 at Project D. This factor alone would cause variation of strength ranging from 100 % to 180 %. As for Project E, in spite of the improved quality of the coarse aggregate, strength may still range from 100 % to 160 %.

Analysis has shown that the effect of the volume batching of the aggregates is less than that of the variability of the coarse aggregate alone.

The fine aggregate was found satisfactory in respect of uniformity of grading, but as an additional factor it has caused even wider fluctuation.

Experiments<sup>8</sup> have shown that reduced fluctuation in grading of the coarse aggregate, batching of aggregates in gauge boxes of relatively small cross-section and that of cement by weight, and maintenance of the mixing water within  $\pm 15\%$  (wide limits indeed) — resulted in a reduction of the coefficient of variation from 23.5% to 18%.

*The average strength and cement content required for ensuring the specified strength under different control conditions*

The statistical analysis of strengths of concrete is generally based on the assumption that their distribution is normal, while the actual distribution is logarithmic-normal<sup>9</sup>. This discrepancy has no practical significance in the case of concretes with a low coefficient of variation, but in calculating the average strength required for ensuring a selected minimum under fair or bad control conditions, the assumption of normal distribution of strength results in excessively high figures, as the author and co-worker<sup>10</sup> were able to verify.

The concretes discussed in the present paper fall into the "good", "bad" or "very bad" categories, so that the calculation of the average strengths required has been based on log-normal distribution of concrete strengths. In Table VI, the average strengths required for ensuring that 99% or 90% of all strengths fall above 120 kg/cm<sup>2</sup> are given, and the corresponding cement content estimated.

TABLE VI  
*Average strength and cement content required under different control conditions*

	Project		
	F	D	G
Coefficient of variation (%)	14	23.5	33
Average strength required for 99% of all strengths to fall above 120 kg/cm <sup>2</sup>	170	215	275
Cement content (kg/m <sup>3</sup> ) required for 99% of all strengths to fall above 120 kg/cm <sup>2</sup>	220	330	410
Average strength required for 90% of all strengths to fall above 120 kg/cm <sup>2</sup>	145	170	195
Cement content (kg/m <sup>3</sup> ) required for 90% of all strengths to fall above 120 kg/cm <sup>2</sup>	200	270	290

Based on the assumption of a Gaussian distribution, the average strength required for 99% of all strengths to fall above 120 kg/cm<sup>2</sup> at Project F is 180, at Project D — 265 and at Project G — 520 kg/cm<sup>2</sup>.

The requirement for special structures being, as a rule, a specified minimum for 99% of all strengths, and for ordinary structures — for 90% of all strengths, it follows that in the "bad" concrete at Project D and the "very bad" concrete at Project G, the cement content was sufficient for ordinary structures, whereas at Project F it was far in excess, even for the case of 99% of all strengths falling above 120 kg/cm<sup>2</sup>. In Israel, the standard

specification<sup>11</sup> requires a minimum cement content of 280 kg/m<sup>3</sup> (for reinforced concrete), which permits, under reasonable control conditions, the production of B-160 concrete (minimum strength 160 kg/cm<sup>2</sup>) (see Project F) or, if vibrated, B-225 concrete (minimum strength 225 kg/cm<sup>2</sup>), thus permitting higher stresses and reduction of dimensions.

In cases where extra strength is not required, the minimum cement content, often specified because of considerations of corrosion of the reinforcement, cannot be fully utilized. Opinions differ on this point, but experience has shown that there is no danger in reducing the minimum cement content to 240 kg/m<sup>3</sup>, provided other precautions against corrosion are observed<sup>12</sup>. Such a minimum for unexposed structures is also allowed by German standard specifications<sup>13</sup>, while in the U.S. the only requirements are in respect of the water/cement ratio and covering depth<sup>14</sup>, with no requirement as to the cement content. This requirement has also been withdrawn from the standard specifications of several European countries. In any case the observation of a minimum cement content would not in itself guarantee an adequate protection of the reinforcement steel against corrosion, while on the other hand it results in waste wherever the extra strength cannot be utilized. This seems to be one of the many outdated practices in the field of building.

The obvious conclusion is that, on one hand, there is need for a revision of those standard specifications which still prescribe a minimum cement content, and, on the other, builders should be induced to produce controlled concrete with specified properties. Towards this end, provided they assume full responsibility for methods of production used, they should be allowed their own free choice. Control should be maintained by means of testing procedures planned according to statistical rules.

If the use of high-strength concrete becomes widespread or, alternatively, if the requirement of a minimum cement content is withdrawn, considerable economy in cement will become possible, subject to reasonable control on the building site. It is estimated that, on the average, a reduction of 20 — 25% of cement can be achieved, with the required strength maintained and other important properties of the concrete (such as uniformity) actually improved.

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# DESIGN OF PAVEMENT ELEVATIONS FOR ROAD AND RUNWAY INTERSECTIONS \*

E. SHKLARSKY

*Division of Geodesy and Communications, Technion — Israel Institute of Technology, Haifa*

## ABSTRACT

In this article, two methods are described for the determination of pavement elevations for an intersection of two roads or airfield runways. One, suggested by the author and applicable for both roads and runways, is based on the plane intersection surface; the other, applicable for roads only, is based on maintaining a uniform crossfall for the main road.

In the first case, the surface plane is determined geometrically by the two centrelines of the roads or runways intersecting at a given angle. Elevations of points in the plane are determined with the aid of the following trigonometrical formulae, for the normal gradients of the respective centrelines:

$$g'_1 = (g_2 - g_1 \cos \alpha) / \sin \alpha$$

$$g'_2 = (g_1 - g_2 \cos \alpha) / \sin \alpha$$

The section of transition between the plane and the normal crowned section of the road should be long enough to permit the slope of the outer edges of pavement with respect to the centreline not to exceed a certain prescribed limit.

In the second case, both the grade and crossfall are kept uniform for the main road up to its roadline. Centreline elevations for the side road are determined from the lateral section of the main road starting at the roadline, and the transitional crossfalls determined subsequently parallel to the centreline of the main road up to the boundary of the normal cambered section.

In both cases, the calculation is supplemented by longitudinal sections at the edges.

## INTRODUCTION

Two methods are described in this paper for calculating pavement elevations for intersections.

The first method, for roads and runways, suggested by the author, is based on the principle of the plane intersection surface; the second, for roads only, on that of a uniform camber for the main road. Neither has so far been mentioned in literature.

The design problem is not always a mere matter of geometrical solution. It should be borne in mind that it also involves a number of practical requirements, such as

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a satisfactory layout of elevations and gradients, rapid drainage, suitable appearance of the intersection surface (especially at the edges), and maximum possible super-elevation of the curves. As in every design problem, the decisive factor is the ability to satisfy all these requirements, or as many of them as practicable.

### THE PLANE METHOD

The plane method permits an easy and unambiguous solution for any kind of gradient. Its main advantage lies in its suitability for high-speed traffic, such as that of modern aircraft on runways, where safety considerations necessitate a high degree of accuracy of design.

#### *The method*

The intersection surface is designed as a continuous plane determined geometrically by the two intersecting centrelines.

Let  $OA$  be one centreline with gradient  $g_1$ ,  $OB$ —the other centreline with gradient  $g_2$ . Their angle of intersection is  $\alpha$ , measured in the plane (see Figure 1).

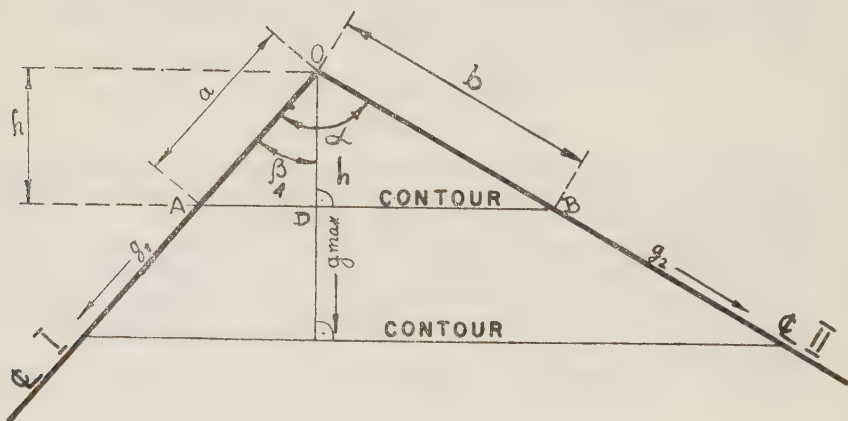


Figure 1  
Plane of intersection

The direction of the maximum gradient in the plane of intersection is that of the normal to the contour lines in the plane. These are determined by laying off segments  $a$  and  $b$  along the centrelines, such that

$$\frac{a}{b} = \frac{g_2}{g_1} \quad (1)$$

(i.e., so as to have equal differences of elevation,  $ag_1 = bg_2$ ).

Denoting the distance between  $O$  and  $D$  by  $h$ , and their difference of elevation by  $z$ , we shall have

$$g_{max} = \frac{z}{h}$$

Moreover,  $z = ag_1 = bg_2$ , and it can also be shown that

$$= \frac{ag_1 \sin \alpha}{\sqrt{g_1^2 + g_2^2 - 2g_1g_2 \cos \alpha}} \quad (2)$$

Hence

$$g_{max} = \frac{\sqrt{g_1^2 + g_2^2 - 2g_1g_2 \cos \alpha}}{\sin \alpha} \quad (3)$$

Let  $\beta_1$  be the angle between the maximum gradient and centreline I. We have

$$\cos \beta_1 = \frac{h}{a} = \frac{ag_1 \sin \alpha}{a\sqrt{g_1^2 + g_2^2 - 2g_1g_2 \cos \alpha}}$$

or

$$\cos \beta_1 = \frac{g_1}{g_{max}} \quad (4)$$

For a variable angle of intersection, *the minimum value of a maximum gradient* can be determined by equating the derivative of function (3), with respect to  $\alpha$ , to zero. We then have

$$\cos^2 \alpha - \frac{g_1^2 + g_2^2}{g_1g_2} \cos \alpha + 1 = 0$$

or

$$\cos \alpha = \frac{1}{2g_1g_2} [(g_1^2 + g_2^2) \pm (g_1^2 - g_2^2)]$$

Hence

$$\cos \alpha_1 = \frac{g_1}{g_2} \text{ for } g_1 < g_2 \quad (5)$$

and

$$\cos \alpha_2 = \frac{g_2}{g_1} \text{ for } g_1 > g_2 \quad (6)$$

Finally, by (3),



$$\text{Min } g_{(\max)1} = g_2 \quad (9)$$

and

$$\text{Min } g_{(\max)2} = g_1 \quad (10)$$

In order to determine the *gradient* normal to centreline II, a perpendicular  $EF$  drawn through  $E$ , cutting centreline I at  $F$  (see Figure 2). We then have

$$f = c \sin \alpha$$

$$d = c \cos \alpha$$

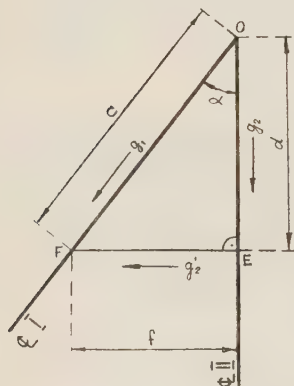


Figure 2  
Plane of intersection — calculation of normal gradient

The respective differences of elevation between  $O$  and  $E$ , and  $O$  and  $F$ , being  $dg_2$  and  $cg_1$ , the difference of elevation between  $E$  and  $F$  is

$$cg_1 - dg_2 = cg_1 - cg_2 \cos \alpha = c(g_1 - g_2 \cos \alpha)$$

and thenormal gradient

$$g'_2 = \frac{c(g_1 - g_2 \cos \alpha)}{f} = \frac{c(g_1 - g_2 \cos \alpha)}{c \sin \alpha}$$

or

$$g'_2 = \frac{g_1 - g_2 \cos \alpha}{\sin \alpha} \quad (9)$$

Similarly, for centreline I,

$$g'_1 = \frac{g_2 - g_1 \cos \alpha}{\sin \alpha} \quad (10)$$

These gradients will be referred to as the normal gradients.

### The procedure

Figure 3 shows two centrelines of roads intersecting at an angle  $\alpha$ . The respective gradients  $g_1$  and  $g_2$ , the elevation of the centre of intersection  $O$ , the widths and minimum curve radii, are all given.

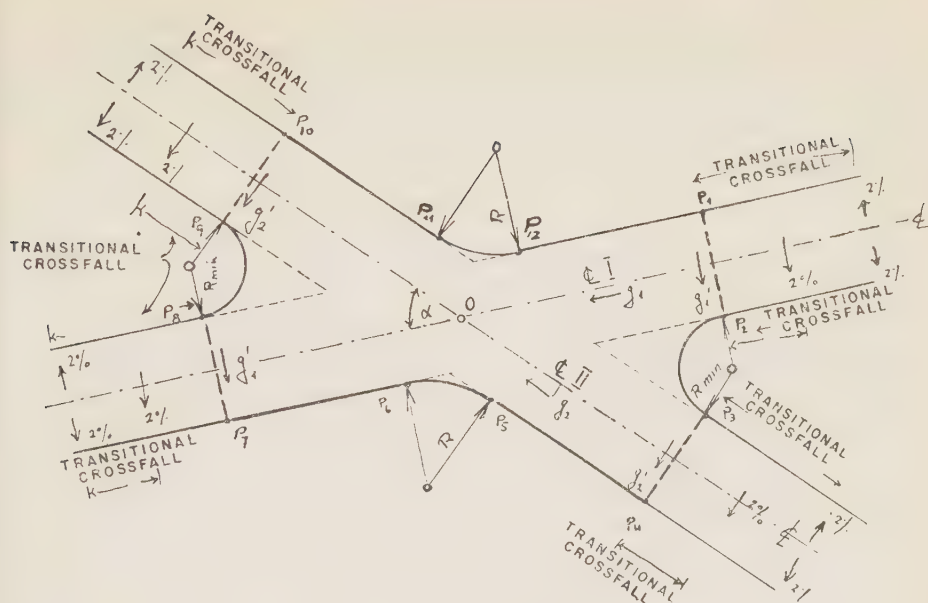


Figure 3

Plane of intersection — transitional crossfalls.

The calculation will be carried out as follows:

- (1) Elevations on the centrelines are determined at desired or specified intervals.
- (2) A plane is drawn through the centrelines, its boundary preferably determined by the points of tangency of the curves bounding the largest intersection surface ( $P_1, P_2, \dots, P_{11}, P_{12}, P_1$  in Figure 3), or otherwise as necessitated by local conditions.
- (3) The normal gradients  $g'_1$  and  $g'_2$  are calculated and the maximum gradient in the plane determined (in order to ensure that it does not exceed the prescribed limit).
- (4) Point elevations in the plane are calculated with the aid of the normal gradients  $g'_1, g'_2$  at intervals determined to scale from the plan, as well as along the curves and elsewhere as required.
- (5) The transitional crossfalls are determined from the boundary of the plane to that of the normal crowned pavement. (The rule in determining the transitional crossfall is that the difference of gradient at the outer edge of the pavement, with respect to the centreline, should not exceed a certain limit. For roads with a speed limit of 35 km/h (urban or built-up areas) this limit is 1%; for roads with a speed limit of 70 km/h, it is  $1\frac{1}{2}\%$ .)
- (6) The longitudinal section along the edges of intersection (drawn to a distorted scale, e.g. length 1 : 200, height 1 : 10) is corrected where required so as to obtain complete continuity. (While continuity is assured in the plane, breaks are possible in the transitional sections.)

(7) In case of a one-sided intersection (see Figure 4), the plane can be confined to the lower side of the road I, provided the crossfall  $g'_1$  does not exceed a certain limit (so as to avoid excessive convexity at the crown of road I). As the limit in practice,  $g'_1$  should be 4%, compared with 2% in the upper side. If higher, it is preferable to include the upper side in the plane.

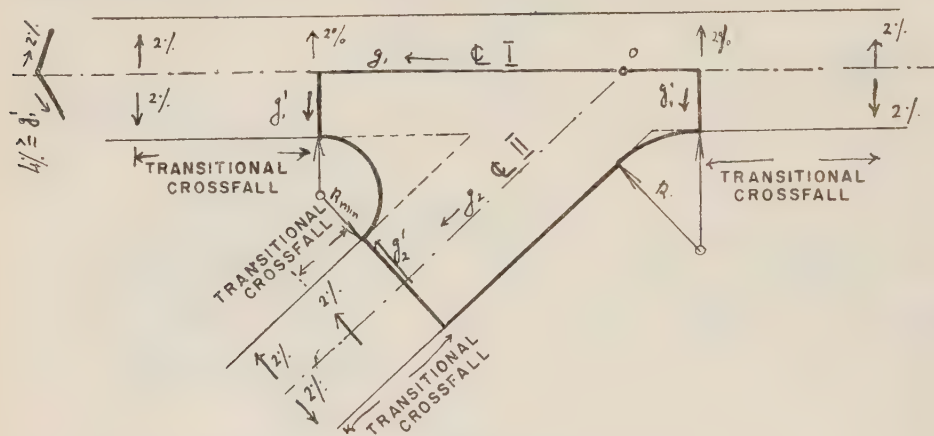


Figure 4

One-sided intersection (plane confined to lower side of road I).

### Example (Figure 5)

Road width = 7.00 m;  $\alpha = 75^\circ$ ;  $g_1 = 4\%$ ;  $g_2 = 5\%$ ; minimum curve radii:  $R_1 = R_3 = 15.00$  m,  $R_2 = R_4 = 20.00$  m; elevation of the centre of intersection = + 10.00 m.

The perpendicular gradients will be

$$g'_1 = \frac{5 - 4 \cos 75}{\sin 75} = 4.10\% \quad g'_2 = \frac{4 - 5 \cos 75}{\sin 75} = 2.80\%$$

and the maximum gradient in the plane

$$g_{\max} = \frac{1}{\sin 75} \sqrt{4^2 + 5^2 - 2 \times 4 \times 5 \cos 75} = 5.73\%$$

As mentioned above, the transitional crossfalls are determined so that the difference of gradient with respect to the slope at the centreline does not exceed 1% in built up areas and  $1/2\%$  in open country.

Point elevations in the plane can be determined with the aid of the calculated normal gradients  $g'_1$  and  $g'_2$  from either centreline, and their geometric position determined to scale from the plan.

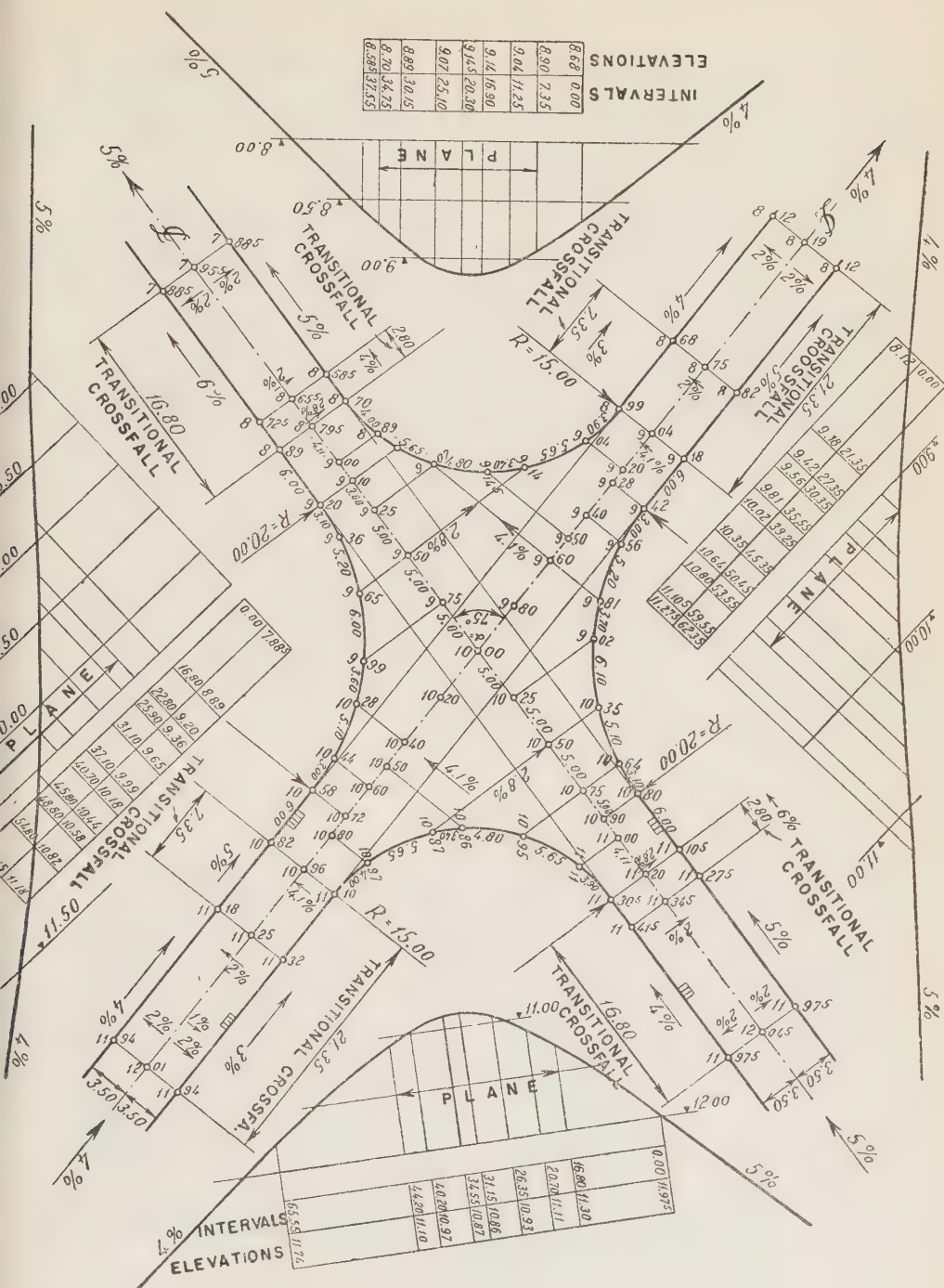


Figure 5  
Plan of elevations — plane method.



## THE UNIFORM MAIN-ROAD CAMBER METHOD

This method is based on maintaining a uniform camber (and if possible a uniform grade as well) for the main road, without transitional crossfalls at the edges, to permit free flow of traffic over the intersection. Gradient adjustments are thus confined to the side road.

For the side road the procedure is as follows:

The first step is the design of the intersection surface outside the roadlines of the main road. The crossfall of the side road is thus adjusted parallel to the grade of the main road and, by means of transitional crossfalls, to its normal cambered section, beginning either at the roadline or at the boundary of the curve.

As for the grade of the centreline of the side road outside the roadline of the main road (up to the roadline — the longitudinal grade of the side road equals the crossfall of the main road), it is adjusted, in the case of a right-angled intersection, parallel to that of its own centreline, with the aid of a vertical curve. The longitudinal sections at the edges are drawn to a distorted scale and corrected for continuity where required. As a result, the intersection surface outside the roadline of the main road consists of a series of planes, with their grades parallel to that of the centreline of the side road, and the crossfalls — to the grade of the centreline of the main road.

For an *acute-angled* intersection, the normal camber of the main road (2%) should be perpendicular to the centreline of the main road up to its roadline. Outside the roadline, the crossfalls of the side road are determined parallel to the centreline of the main road, at intervals determined to scale from the plan, and transitioned, as explained above, to a normal camber.

*Example*

Grade of main road = 6%; crossfall = 2%; width = 7.00 m; width between roadlines = 18.00 m; width of side road = 7.00 m; angle of intersection = 65°; elevation of centre of intersection = + 10.00 m; grade of side road (outside surface of intersection) = 3%; minimum curve radius = 15.00 m.

(1) The longitudinal section of the side road, at the centreline, is designed with a uniform crossfall maintained for the main road (2% perpendicular to its own centreline, or 4.35% parallel to the centreline of the side road). For this purpose, a vertical transitional curve is provided between the 3% and 4.35% sections. In such cases, comparatively short tangents can be used, but unless unavoidable the transitional section should not begin inside the roadline.

(2) The crossfall of the side road, in a direction parallel to the centreline of the main road, will be equal to the grade of the latter (6%) up to the roadline. Outside the roadline there would be two alternatives:

(a) A uniform 6% crossfall maintained up to the *point of tangency* of the curve, with a transitional crossfall up to the boundary of the normal cambered surface.

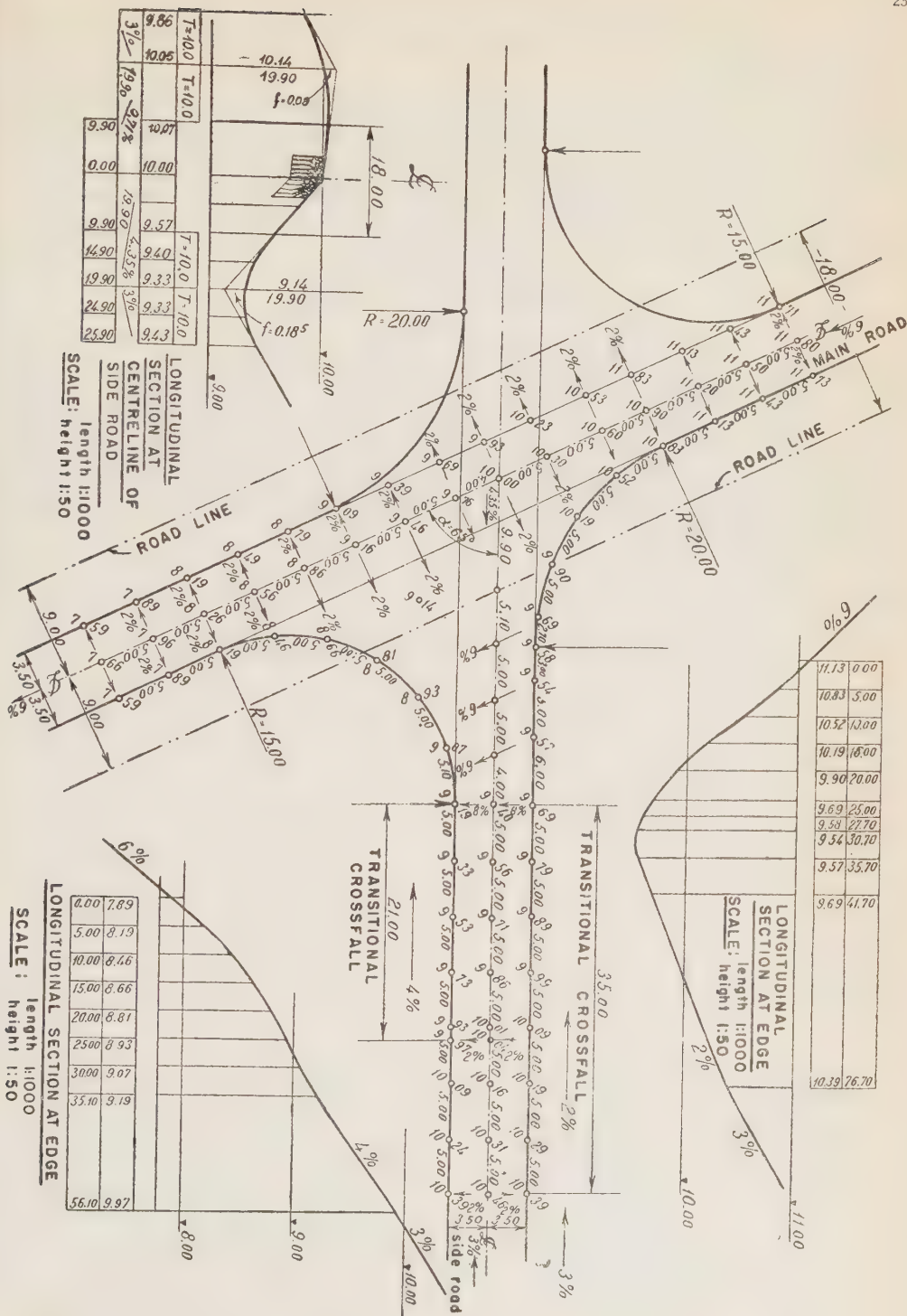


Figure 6  
Plan of elevations — uniform camber method.

(b) A transitional crossfall from the *roadline* up to the boundary of the normal cambered surface.

The first alternative, used in this case, is preferable from the geometrical point of view, as it entails no discrepancies in edge elevations calculated from different directions, and thus necessitates fewer corrections for continuity at the edges.

The plan of elevations is shown in Figure 6. The crossfall of the side road (perpendicular to its centreline) at the point of tangency of the curve was calculated as

$$g_2' = \frac{g_1 + g_2 \cos \alpha}{\sin \alpha} = 8\%$$

(the plus sign due to the negative  $g_1$ ).

In conclusion, it can be said that the plane method has clear advantages over the uniform crossfall method. It permits the layout of the intersection within a smaller space and (especially important in runways) provides continuity in *all* directions. Besides, it should be borne in mind that a side road may develop into a main road and in this case an impeded traffic flow cannot be avoided in an intersection designed by the uniform camber method.

## ROADS IN ISRAEL

### RECENT TRENDS IN PLANNING AND CONSTRUCTION

J. L. A. WATSON

*Chief Roads Engineer, P.W.D.*

During the British mandate in Palestine, from 1918 to 1948, a network of asphalted arterial and district roads was built with the object of connecting all urban centres.

This network forms the basis of the country's road net to-day. However, wide changes were undertaken since 1949 because of the new orientation in planning. In the first place, all arterial roads until 1948 were planned to give quick and easy access to the principal towns in the neighbouring countries. To-day this is of secondary consideration to the problem of easy access to industrial and market centres within Israel itself. The other change is due to the revolution in agricultural development. In the past seven years agriculture has become highly mechanized, with the result that an all-weather approach road to every village, whether new or long established, has become a necessity. These village roads in turn have required the construction of a net of feeder roads to connect them to the national road system.

The boundaries of the new State created a situation whereby some former arterial roads became of very minor importance, e.g. the Tel Aviv — Ramle — Jerusalem road between Ramle and Sha'ar Hagai; the Nazareth-'Afula-Jerusalem road from 'Afula southwards to the frontier; the Haifa-Beirut road north of Nahariya, and others.

In turn some roads, formerly of very minor importance, suddenly became sections of arterial roads of first importance. All this demanded careful planning of the future functions of all roads in the country.

A start was made in 1950 by the Public Works Department of the Ministry of Labour, by working out a suitable scheme of classification. The system finally adopted is based partly on the British system and partly on the French system.

Roads are classified into four groups: (1) arterial roads, RED on plan; (2) district roads, BLUE on plan; (3) local roads, GREEN on plan; and village approach roads, uncoloured.

This scheme was combined with re-marking the kilometre stones throughout the country. Formerly all main roads were measured from Jerusalem. Under the new system arterial roads are numbered from seven urban centres — Jerusalem, Tel Aviv, Haifa, 'Afula, Tiberias, Migdal Ashqelon and Beersheba. The district roads are numbered from their arterial road connection and, similarly, local roads are numbered from their district or arterial road connection.

Just as these roads are coloured red, blue and green on the road map, so the tops of kilometre stones are painted red, blue and green, in order to indicate the class of road



at a glance. At the same time the number of each road, in its respective colour, is affixed to the arms of signposts.

The next stage in planning the widening and improvement of existing roads, and the necessity for new roads, was to determine the present volume of traffic and estimate anticipated increases from the development plans of the Ministry of Interior's Planning Department. In March each year a country-wide traffic census is undertaken, with "Origin and Destination" surveys conducted at certain key points.

The most heavily trafficked road carries 24,000 vehicles of all types per day.

The extensive length of Israel in proportion to its width, coupled with Government's declared policy of distributing the population throughout the country, called for the planning and early construction of new North-South arterial roads.

The most important of these is road No. 11, from Tel Aviv northwards to Natanya and Kfar Vitkin, joining road No. 12 north of Hadera. This road lies west of the railway line throughout its length.

Of almost equal importance will be road No. 13, from Rishon-le-Zion northwards to Azur and Bnei Braq, joining road No. 12 at Ra'anana. This road will enable north-south traffic to by-pass Tel Aviv and its densely populated suburbs. A future link from the main road to Beersheba, No. 81, will join road No. 13 between Yibneh and Rishon-le-Zion, enabling north-south traffic to avoid built-up areas.

An extensive net of main and district roads links up these arterial roads and connects industrial and agricultural centres.

The most important main road constructed in recent years in the Negev is the 78 km asphalted road, designed to modern standards, linking Beersheba with Sdom on the Dead Sea. This road took four years to plan and build. The most difficult problem which faced the engineers who designed the road, was how to overcome the difference in levels between Mamshit (Kurnub) 440m above sea level, and Sdom 412 m below sea level. This was aggravated by the fact that the ground dropped 320 m in three kilometres. On this section two especially difficult features were encountered. At one point there was a chasm 300 m long and 26 to 30 m deep, between two walls of marble sloping at an angle of 40°. This chasm had to be filled with rock blasted from the surrounding mountains.

At another point on this section a vertical cliff of dolomitic limestone 38 m high was encountered. In order to overcome the obstacle 22,000 m<sup>3</sup> of rock had to be blasted away and a further 35,000 m<sup>3</sup> of rock had to be brought in as additional "fill".

Another Negev main road of more than usual interest is the central road, from Kfar Yeroham running almost due south, past Sde Boqer and 'Ovdatt to join the 'Arava road at Beer Menuha, 90 km north of Eilat. The road was built by the engineering corps of the Israel Defence Army. It was designed to a high standard but, to date, has been given an asphalt surface on short sections only.

In proportion to the length of roads existing in 1948, there has been an increase of 50% in the total road net as of January 1956.

New roads completed in the past seven years, or now under construction are:—main roads 362 km; district feeder roads 638 km; approach roads to villages 552 km.

No less dramatic has been the change in construction methods introduced in recent years.

The task is to build as large a mileage of new roads as possible within a strictly limited budget. The problem is aggravated by the fact that soil conditions vary greatly

Design standards in use are shown in Table I.

TABLE I

\* These figures are relaxed somewhat in mountainous areas.

The laboratory now provides the answer to these problems. Samples of soil found on the alignment of the road, to a depth of two metres, and soil to be used for the embankment are sent to the laboratory. There it is decided whether the existing soil has to be compacted in its natural state, or mixed with imported granular material, or be completely removed.

A soil is sought for the embankment which has a liquid limit under 30 and a plasticity index between 5 and 9. Having found the suitable soil, the laboratory fixes the optimum moisture at which the soil must be compacted in order to obtain the maximum density. Specifications call for a field density of 90 to 100% of the maximum density, according to the nature of the soil.

Before any "fill" is deposited, all vegetation and organic matter, to a depth of 20 cm in the "top-soil", is removed.

The embankment is built to-day entirely with mechanical equipment.

Clay soils are compacted by "Sheepsfoot" rollers, up to one ton individual sections, so built that the whole weight falls on not more than two feet at one time.

Multiple wheel rubber tyred rollers are used for compacting granular soils. Six to twelve tons is the usual weight of these rollers.

Specifications call for spreading soil for the embankment in layers not exceeding 20 cm in depth. In order to reach the required density it is usually more profitable to spread and compact the soil in thinner layers of 15 or even 10 cm depth, at optimum moisture content.

The thickness of the sub-base, base and wearing surface of the road are determined by the California Bearing Ratio (CBR) method.

The aim is to find a relatively cheap local material for the sub-base so as to reduce to the minimum the quantity of expensive crushed stone which has to be transported to the site.

The CBR test can be a valuable tool for determining what local materials are suitable as a sub-base or base in road construction as well as for deciding the actual thickness which should be employed.

There is a wide range of natural materials which are indeterminate in strength between the average type of soil found in our subgrades and the limestone normally used in bases. We must exploit these cheaper materials to the maximum degree possible.

The best known and most used of these natural materials are:

- (a) Metamorphosed basalt (called "Hizri").
- (b) Calcareous sandstone (called "Kurkar").
- (c) Gravel occurring in beds and banks of streams.

Each of these materials varies greatly from deposit to deposit and, in consequence, constant laboratory and field control is essential to their use. For example, "Hizri" often contains excess clay; the "Kurkar" may have an excess of clean sand without binding properties, while the gravel may vary from clean round pebbles to a highly plastic material.

However, each of these materials has been used very extensively in road building in Israel in recent years and has given highly satisfactory results.

It is likely that we have by no means exhausted the possibilities of using other local materials, either alone or in combination with other soils. Care should be taken not to reject materials just because they have not previously been used, or because in the past they have been thought to be unsatisfactory.

As an example of the use of the CBR method in finding local materials, we can assume that a main road has to be built on a clay subgrade having a CBR value of



4 percent. Reference to the appropriate design curve (5,000 kg wheel load) will show that a total thickness of construction of 50 cm is required. It would clearly be uneconomical to build up this thickness entirely from expensive material like crushed stone. Therefore further CBR tests are made on samples of cheaper local materials. We may find that we have nearby a "kurkar" with a CBR of 18 and a sandy gravel with a CBR of 28. Referring again to the chart we see that "kurkar" value 18 requires 30 cm above it, while gravel value 28 requires 15 cm above it. We can therefore build our road of 20 cm depth of kurkar, covered by 15 cm depth of gravel, 8 cm depth of 4 cm gauge stone base (waterbound or grouted with bitumen) and 7 cm of bituminous pavement.

It was assumed, until recently, that the CBR of the crushed stone base must reach 80%. It is now claimed that uniformity is of paramount importance and that, provided the stone base does not show a CBR value of less than 60% at any point tested, it may safely be covered by 5 cm of asphalt concrete, in order to carry normal main road traffic.

Dense graded hot mix, hot laid, asphaltic concrete paving was used for the first time on Israel's main roads in 1955. 35 km were laid between Beersheba and Dimona and 5 km between Tel Aviv and Haifa. The results seem to be excellent and the use of this type of paving will be greatly extended during the coming year.

The design mix shall conform to a "job mix" formula based on one of the following gradation tables:—

TABLE II  
*Gradations for asphalt mix*  
*Surface course (%)\**

Sieve size	Band No.	1 inch maximum			3/4 inch maximum		
		1	2	3	1	2	3
1 inch		100	100	100			
3/4 "		85—100	87—100	90—100	100	100	100
1/2 "		72—87	76—89	82—93	86—100	89—100	91—100
No. 4		45—60	52—67	60—75	55—67	61—74	67—80
No. 10		32—47	39—54	47—62	40—54	46—60	54—66
No. 40		16—26	21—32	26—37	22—31	26—35	31—40
No. 80		10—18	13—21	16—24	12—20	15—23	19—26
No. 200		4—8	4—8	5—9	4—8	4—8	4—8

\* All percentages of aggregate and bitumen are by weight.

*Binder course*

Sieve size	Band No.	1 inch maximum			3/4 inch maximum		
		1	2	3	1	2	3
1 inch		100	100	100			
3/4 "		76—100	80—100	85—100	100	100	100
1/2 "		64—82	67—85	71—89	74—100	80—100	82—100
No. 4		38—54	43—59	48—64	42—60	47—65	52—70
No. 10		25—41	29—45	34—50	28—46	33—51	36—54
No. 40		12—23	14—25	17—28	14—26	16—28	18—30
No. 80		7—16	8—17	10—18	8—18	9—19	10—20
No. 200		4—8	4—8	4—8	4—8	4—8	4—8



The job mix shall conform to the selected gradation within the following tolerance:—

Aggregate passing sieve No. 4 and larger	± 5%
Aggregate passing sieve No. 10	± 3%
Aggregate passing sieves Nos. 40 and 80	± 2%
Aggregate passing sieve No. 200	± 1%
Bitumen straight run 80/100 penetration	± 0.3%

The usual thickness of an asphalt concrete layer varies from 2 cm to 5 cm. The gauge of the largest sized stone in the mix should not exceed half the thickness of the finished pavement.

Aggregate must be heated to a temperature of 325°F when delivered to the mixer. Bitumen must reach a temperature of 300°F in the mixer.

The distance of haulage between plant and site of work is conditioned by the fact that the mixed material must show a minimum temperature of 225°F when laid. In summer weather conditions in Israel this restricts the distance by road to 40 km if delivery is in open trucks and 60 km in covered trucks.

Laying must be carried out by a mechanical spreader. The heat at which the mixture is laid, coupled with the rapidity with which it sets, rules out any possibility of hand spreading.

This asphaltic concrete pavement gives a completely water tight surface at a cost slightly less than that of the former popular type of bituminous macadam pavement which was by no means water resisting. However, bituminous macadam is easy to patch and repair. It will therefore be used where the road foundation is not stable. Asphaltic concrete is very difficult to repair. The only effective measure is to burn off the layer and renew it. Asphaltic concrete will therefore be restricted in its use to roads with strong foundations.

For district and local roads in agricultural areas and in the Negev, where a cheap bituminous carpet is required, a gravel-bitumen road mix has been successfully used. The riding surface of such a road is not particularly smooth but it prevents the generation of mud and dust and is easy to repair. As the aggregate is local gravel it can effect an important saving in cost where suitable road stone quarries are not available. The materials used for this type of pavement are wadi gravel and a cut-back bitumen M. C. 3—5 grade.

The best results are obtained if the gravel is crushed, screened and graded 1 1/4" to dust. Satisfactory results have also been obtained with gravel in its natural state. However, in this case great care must be taken to ensure that the plasticity index does not exceed 8, that stones larger than 2" and an excess of round stones are removed. This adds considerably to the cost, so that it may be assumed that it is usually worth while to crush, screen and grade the gravel, particularly as this also aids the drying process.

Gravel is spread in a windrow at the side of the road bed, the quantity of gravel being calculated in accordance with the finished thickness of pavement — usually 8 cm after compaction.

Before bitumen is applied moisture content of gravel must be reduced to 2%. This can be done by spreading the gravel on the road bed in a thin layer by means of the motor grader and allowing moisture to evaporate.

The cut-back bitumen is sprayed onto the windrow in three separate applications. The material is turned over by a motor grader and well mixed between each application of bitumen. The quantity of bitumen required is in the range of 90 kg per m<sup>3</sup>. Thorough mixing is essential and it is desirable to use a harrow or discus to aid the motor grader in mixing the bitumen with the gravel.

After spreading to finished camber by the motor grader, rolling is done by a 6 to 10 ton pneumatic tyred roller. The final shaping is done by a steel wheel roller working from the sides towards the centre of the road. The rear wheels overlap half a wheel width at each pass.

In sections of the country where the soil comprises loess or sandy loess, a cheaper type of rural road has been tried with some success.

A minimum of excavation and fill is done with self-propelled scrapers. The surface is shaped and brought to camber by a motor grader. Magnesium chloride and calcium chloride, from the Dead Sea, in the proportion of 4 of the former to 1 of the latter, in a 40% solution is sprayed onto the prepared road bed, using 2½ gallons of solution per m<sup>2</sup>. After about one month a further treatment is applied using one gallon of the same solution per m<sup>2</sup>. The cost is about one-sixth of that of a conventional type road. On straight sections of the road so treated a private car can travel comfortably at 80 km an hour without raising dust. On bends there has been some ravelling which can be largely obviated by providing steep superelevation to reduce the centrifugal force.

In temperate climates calcium chloride alone has been used with considerable success. In a dry climate, however, such as the Israel Negev, the liquefying action of magnesium chloride added to the hygroscopic nature of the calcium chloride seems to give the best results.

The above notes indicate recent trends in road building in Israel. The Central Laboratory of the Public Works Department will be used in extensive experiments in the future to find ways of building good roads, cheap in initial cost and cheap to maintain.



PROCEEDINGS  
OF THE  
FOURTH MEETING  
OF THE  
ISRAEL ASSOCIATION  
FOR  
THEORETICAL AND APPLIED  
MECHANICS

HELD AT HAIFA, APRIL 14, 1956  
AT THE  
TECHNION — ISRAEL INSTITUTE OF TECHNOLOGY





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## Morning Session

**The hydrodynamics of dispersions**, A. PETERLIN, *University of Ljubljana, Yugoslavia.*

**On the impossibility of simple viscous flow in space, with few exceptions**, S. IRMAY, *Technion—Israel Institute of Technology, Haifa.* Viscous flow of incompressible fluids obeys the non-linear Navier-Stokes equations, of which only few solutions are known. The author shows that this is due not only to mathematical difficulties, as in the presence of solid boundaries there exist no stable solutions corresponding to simple flows.

A simple flow line is defined as the intersection of any two surfaces of a triple mutually orthogonal system of curved surfaces; or as the flow line of any potential flow net. Thus radial flow inside or outside a conical surface is impossible.

Neglecting the non-linear terms, the so-called approximate solution is obtained. This shows how careful one has to be when any term is neglected in the differential equations.

The proof is obtained by defining as  $a/m$  a simple type of flow and introducing this into the Navier-Stokes equations or rather into their compatibility conditions. The solution is expanded into a Taylor series in the neighbourhood of a solid boundary. The flow is then shown to be impossible or unstable, as its velocity profile has a point of inflexion (Rayleigh-Tollmien condition of instability).

Among the few exceptions to this rule are cases of two-dimensional flow; or the flow in a cylinder parallel to its generatrix.

This explains why any laminar flow has a ten-

dency to twist and become complicated, which may throw some light on the genesis of turbulence.

**Economic water duty**, M. RAM, *Ministry of Agriculture.* Thorough analysis of possible means for the production of high agricultural yields shows that such yields, more than 7.5 times higher than the dry farming average, may become possible if the following factors are complied with: (i) agrotechnical and irrigation methods for raising soil fertility; (ii) suitable chemical fertilization; (iii) crop rotation suitable to climatic conditions, in order to reduce water duties, in full agreement with the effective use of natural precipitation; (iv) utilization of the principle of fixed amounts of water, as a lot viable.

"Fixed amount of water" is defined as a certain amount of water which serves, as a lot viable, under the presumption that the plot at the farmer's disposal is comparatively large and that it is impossible to irrigate it intensively with the limited amount of water at his disposal.

The effects of agrotechnical methods and of chemical fertilization are discussed. Stress is laid on climate as an important factor influencing the principle of fixed amounts of water.

The problem is studied from the mathematical-economical point of view, relying on the results of experiments carried out in various parts of the world.

Various alternatives are examined diagrammatically and clear conclusions are drawn concerning the limitations of the use of the principle of fixed amounts of water under certain economical and geographical conditions.

## Afternoon Session

**On isotropic tensor functions and the measure of deformation**, M. HANIN, *Technion—Israel Institute of Technology, Haifa.* It is shown that an isotropic relation between two symmetric tensors of second rank can be expressed in the form

$$\begin{aligned} y_s^r = & (\mathcal{F}_0 + \sum_{n=3}^{\infty} \mathcal{F}_n C_n) \delta_s^r + \\ & + (\mathcal{F}_1 + \sum_{n=3}^{\infty} \mathcal{F}_n B_n) x_s^r + \\ & + (\mathcal{F}_2 + \sum_{n=3}^{\infty} \mathcal{F}_n A_n) x_\alpha^r x_s^\alpha, \end{aligned}$$



where

$$\mathcal{F}_n = \sum_{p,q,r} k_{p,q,r}^{(n)} I^p II^q III^r,$$

and the  $A_n$ ,  $B_n$ ,  $C_n$  are similar power series in the principal invariants of  $x'_s$ . The constants  $k$  must be determined by means of suitable experiment between the physical quantities represented by  $x'_s$ , and  $y'_s$ . The  $\mathcal{F}_n$  may, however, also be constants. This is for instance the case when  $x'_s$  and  $y'_s$  are different measures of deformation. We are then able to express for instance the logarithmic Hencky-measure through the Almansi measure. When this is done a quasi-linear stress-flow relation will reveal certain second order effects in viscous liquids, even when elasticity is absent, and the viscosity is low. This may provide a theoretical understanding for a centripetal pump effect in air, as recently observed.

**Simplification of formulae and graphical solutions for a single span beam**, E. BEN-ZVI, *Technion—Israel Institute of Technology, Haifa*. Substitutions and graphical solutions are presented for simplifying the calculation of shear, moments, slope and deflections of a single span beam. The graphical solutions for moments are based on circles, the ordinates of which represent the square roots of the moments, instead of the conventional parabola representing moments directly. These methods may be of practical value in the calculation of moments of an internal span of a continuous beam, and in other cases for the calculation of deflection and slope by a uniformly distributed load.

**A centripetal pump effect in air**, M. REINER, *Technion—Israel Institute of Technology, Haifa*. An instrumental setup is described which constitutes a centripetal air pump. It is shown that the phenomenon can be explained on the assumption that air is viscoelastic as foreseen by Maxwell, with an elastic strain as defined by Hencky.

**A solution for partially constrained beams**, M. MITTELMAN, *Technion—Israel Institute of Technology, Haifa*. The hinged and fixed supports of theory hardly ever occur in practice, and every support may be considered as partially built-in.

It is possible to measure the elastic constraint  $\tau$  as a part of a total constraint  $\tau = 1$ , using the relation between the angles of deflection  $\varphi_\tau$ , when the support provides a constraint  $\tau$  and  $\varphi_0$ , when the support is a hinge ( $\tau = 0$ ):

$$\varphi_\tau = (1 - \tau)\varphi_0.$$

From this we find in the case of a doubly supported beam, when a force  $P$  acts at a distance  $a$  from one support, that the moment at the support  $A$  is

$$M_A = -\frac{\tau_A}{4 - \tau_A \tau_B} a(1-a) [2(2-a) - \tau_B(1+a)] Pl$$

$$\text{where } a = a/l,$$

and the moment at  $B$  the same with  $a' = 1 - a$ .

If  $\tau_A = \tau_B = \tau$  and  $a = a' = \frac{1}{2}$ , we find

$$M_A = M_B = M = \frac{3\tau}{2+\tau} \cdot \frac{Pl}{8}$$

i.e. the moment at the support is not proportional to the degree of constraint. This method enables one to calculate elastically constrained continuous beams and also frames and arches.

**A new indirect tension test for concrete**, S. ROSENHAUPT, *Technion—Israel Institute of Technology, Haifa*. The test consists in applying a compressive load along the middle of two opposite faces of a concrete cube. The cube fails in tension along the plane containing the load.

The investigation was made in three steps:

(1) *Theoretically*. The plane-strain problem was studied by the method of differences, the system of equations being solved by matrix inversion. The tension along the middle plane is fairly uniformly distributed and its value is:

$$\sigma = 0.648 P/ah$$

$\sigma$  = tensile stress in kg/cm<sup>2</sup>

$P$  = force in kg

$a, h$  = dimensions of the failure section in cm.

(2) *Photoelastic analysis*. A square plate of "catalin" was used. The values of the stresses  $\sigma_x$ ,  $\sigma_y$ ,  $\tau_{xy}$  and the trajectories agreed with the theoretical results.

(3) *Tests on concrete specimens*. Tests were made at the age of 28 days on cubes and cylinders in indirect tension and on prisms. The results confirmed the theoretical previsions.

#### CONCLUSIONS

(1) The new test has proved itself reliable.

(2) It has the advantage of using the same specimens and loading apparatus as for the ordinary compression test.

## ACKNOWLEDGMENTS

The investigation was carried out at the T.N.O. laboratory for structures at Delft (Holland) in collaboration with Mr. A. C. van Riel and L. Wijler. Thanks are expressed to Ir. J. G. Hageman, the Director of the laboratory, for the permission to publish the results.

**The annual heat budget of natural water bodies from the point of view of turbulence theory, J. NEUMANN, *Meteorological Service*.** The annual heat budget of a natural water body (lake, sea) is the part in the heat content of the water body alternating during a yearly cycle (= amount of heat entering into storage in a water column of unit cross-section between the dates of the minimum temperature and maximum temperature of the column).

An examination of data for lakes does not reveal a dependence of the annual heat budget on geographical latitude, contrary to what one would

expect in view of the pronounced latitudinal variation in the intensity of solar radiation. There is, however, a clear indication of dependence on the depth of the lake. The purpose of the note is to clarify the nature of this dependence as far as possible.

The principal tool is Kolmogoroff's similarity theory of turbulence as presented and developed by Batchelor. Assuming a constant rate of energy dissipation per unit mass of water, and assuming that the lake depth  $L$  is neither too great nor too small, we find that the annual heat budget  $Q_h$  should be proportional to the cube root of lake depth, or

$$Q_h \propto L^{1/3}.$$

As a check on the validity of this inference we have examined annual heat budget data for some 75 lakes situated in various parts of the world. The diagram plotting  $Q_h$  vs.  $L^{1/3}$  indicates a moderate scatter of the data about a straight line, confirming, in essence, the validity of the inference.



## BOOK REVIEW

**Handbook of Textile Fibres.** Edited by Milton Harris. Harris Research Laboratories Inc., Washington, D.C. 356 pp. \$ 12.50.

The scientific study of the textile processes has developed rapidly in the last few decades. It received a strong impetus during the Second World War with the development of the synthetic fibres, and a great amount of research was carried out in hundreds of laboratories all over the world. This progress owes much to a relatively small number of books, among which this book will be undoubtedly counted. Harold de Witt-Smith's pioneering work, *Textile Fibres — an Engineering Approach to their Properties and Utilization*, showed to what a large extent the qualities of the finished cloth depend on the properties of the single fibre. E. Kaswell collected, abstracted and published a literature survey in his *Textile Fibres, Yarns and Fabrics*, which contained many of the results obtained up to 1953.

Harris' *Handbook of Textile Fibres* is the first serious attempt to present this vast material summarized in tables and graphs.

The book contains a vocabulary of textile terms and definitions and a comprehensive list of natural and artificial fibres, their sources, composition and manufacturers.

The section dealing with the physical properties of fibres contains information about the various mechanical, optical, electrical, thermal and frictional properties, including stress-strain behaviours, elastic performances, thermal conductivity, flame resistance and permeability, to mention just a few.

The chemical section deals with the various sorption and swelling properties of fibres, contains dyeing and viscosity data, and discusses the effect of weathering and of various chemicals on the fibre. Other sections deal with the action of biological agents, and numerous tables are given containing information on economic aspects and production, on yarn numbering systems, and on identification of textile fibres. A very exhaustive section deals with photomicrography and X-ray diffraction characteristics of textile fibres. The information reported concerning many new synthetic fibres will be especially appreciated.

This excellent handbook is less handy than various electrical, mechanical and chemical engineering handbooks, and the reader will not always be able to find his way in the index. Furthermore, it may sometimes be difficult to choose the most accurate from the various results given. Still, this is the first edition of the first book of its kind, and it should not be missing where serious consideration of fibre properties is attempted.

J. FRIEDLAENDER

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